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## ATB PROGRAM AND ITS APPLICATIONS TO BIODYNAMIC RESPONSE SIMULATION OF UNDERWATER EXPLOSION EVENTS

by

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March 1998

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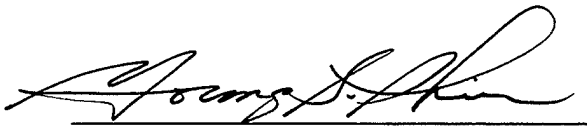
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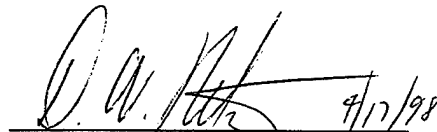
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## **ABSTRACT**

The application of the Articulated Total Body Model Program, and the associated Generator of Body Data (GEBOD), VIEW and IMAGE programs, to the study of biodynamic responses of anthropomorphic test devices and humans to excitations resulting from underwater explosion events is investigated. An overview of each program is presented, and then a single example is followed through the entire modeling and simulation process. Validation and extension of the model, as well as two- and three-dimensional visualization of the predicted body motion, are discussed.



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## I. INTRODUCTION

The response of a ship's structure, and that of the equipment contained within it, to an underwater explosion is a subject that has been extensively studied. However, in evaluating a ship's ability to remain a viable warfighting asset, crew survivability must also be addressed. In order to evaluate crew survivability, it becomes necessary to assess or predict the biodynamic response of shipboard personnel to underwater explosion events, making an already complex task even more difficult. Fortunately, there exists a group of powerful computer simulation programs, the Articulated Total Body (ATB) Model, Generator of Body Data (GEBOD), VIEW, and IMAGE programs, which may be readily applied to the task of predicting and visualizing biodynamic response to underwater explosion events. This report is not meant to be a replacement for the ATB user's guide [Ref. 1], the GEBOD Manual [Ref. 2], or the VIEW user's guide [Ref. 3]. Rather, it seeks to supplement these guides for the new user by elaborating on the application of these programs for both validation of a model using recorded video footage and accelerometer data from actual testing, and for making the extension to predicting biodynamic responses based on the validated model. One example of this application is used throughout the report in order to illuminate the process further.



## II. PROGRAM UNITS

### A. ARTICULATED TOTAL BODY (ATB) VERSION IV

The ATB program is the heart of this group of simulation tools. It is in this program that a model of the shipboard environment is created, the input excitation applied, and the biodynamic response computed. The ATB program may also be used to produce output formatted for use with the VIEW or IMAGE programs for the purpose of two- or three-dimensional visualization, respectively.

#### 1. Program Overview

Primarily designed to simulate the three dimensional response of a system of rigid bodies subjected to dynamic applied and interactive contact forces, the ATB program was originally developed to model the response of crash test dummies. However, it has been used in many varied applications including human body motion, transient response of a MX missile in a wind tunnel, and pilot ejection from aircraft. The program is very general and can be used to model most any system that can be approximated by connected or free rigid bodies [Ref. 1]. The ATB program is written in FORTRAN and may be run from a personal computer (in a DOS window).

Since the ATB program is quite versatile and has a tremendous number of options, this overview cannot hope to adequately cover each one; it serves as a brief introduction to some of the more important and widely used options. The reader is strongly encouraged to refer to Ref. [1] to learn about options and details not covered in this report.

#### a. Representation of bodies

In the ATB environment, the term "segment" refers to an individual rigid element which, when connected to other segments, makes up a body. More than one body may be modeled in a single system, but the total number of segments modeled is limited to 30 by the program [Ref. 1].

Segments are rigid, lumped mass elements with mass and inertial properties that may either defined by the user or may be automatically generated using the GEBOD program if the body being modeled is a human being or an anthropomorphic test device (ATD). The volume that a segment occupies is described by one or more ellipsoids (or hyperellipsoids) that typically match closely the physical dimensions of the actual object that the segment models. These (hyper) ellipsoids also serve as the contact surfaces that are used for calculating the dynamic forces produced through interaction with other segments or the contact surfaces of the environment [Ref. 1]. If the user specifies segments in addition to those generated by the GEBOD program, then the user must provide the weight, principal moments of inertia, any rotation of the principal axes with respect to the segment local reference system, and the lengths of the semi-axes of the ellipsoid for each additional segment.

A body is created from one or more segments connected to each other by joints of various configurations into an open chain or tree structure (although the program does not preclude the construction of a closed chain, computational problems may be encountered [Ref. 1]). Figure 1 summarizes the joint types that are provided for in the

ATB program. If more than one body is specified, then the first segment of the second body would be connected to the last segment of the first body using a null joint. Ball and socket joints are used to represent hip or shoulder, while pin or Euler joints are used to represent knees and elbows. Null joints are used when more than one body is specified.

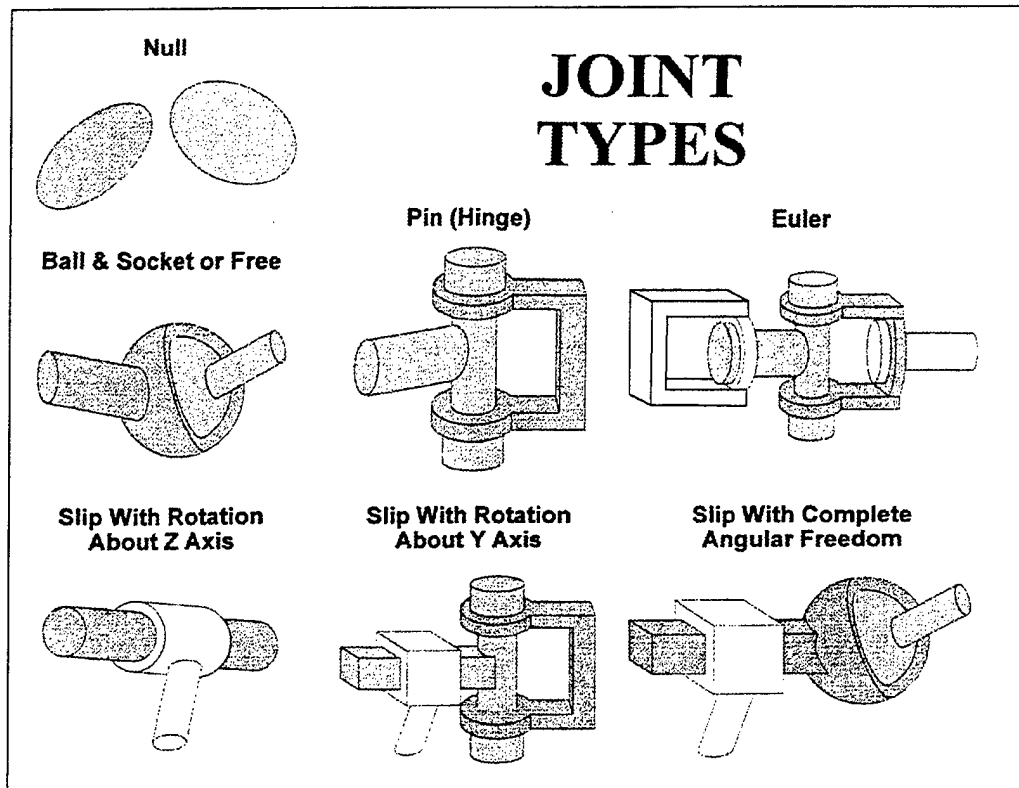


Figure 1. Joint Types Provided for in the ATB Program. From Ref. [4]

For each joint, the user must specify the flexural and torsional spring characteristics, as well as the viscous and coulomb friction characteristics. The torque characteristics, either flexural or torsional, are specified using five parameters: S1, the linear spring coefficient (in-lbs/deg); S2, the quadratic spring coefficient (in-lbs/deg<sup>2</sup>); S3, the cubic spring coefficient (in-lbs/deg<sup>3</sup>); S4, an energy dissipation coefficient between 0 (maximum loss) and 1 (no loss); and S5, the joint stop location (deg) with respect to the center of symmetry of the joint [Ref. 1]. Figure 2 graphically shows the manner in which the torques are computed from these five parameters. The coulomb torque is defined by specifying two parameters: V2, the coulomb friction coefficient (in-lb); and V3, the relative angular velocity (deg/sec) at the joint for which maximum coulomb friction is applied. The viscous torque is defined by simply specifying V1, the viscous coefficient (in-lb-sec/deg). Figure 3 illustrates both the coulomb and viscous torque functions.

# Joint Spring Torque

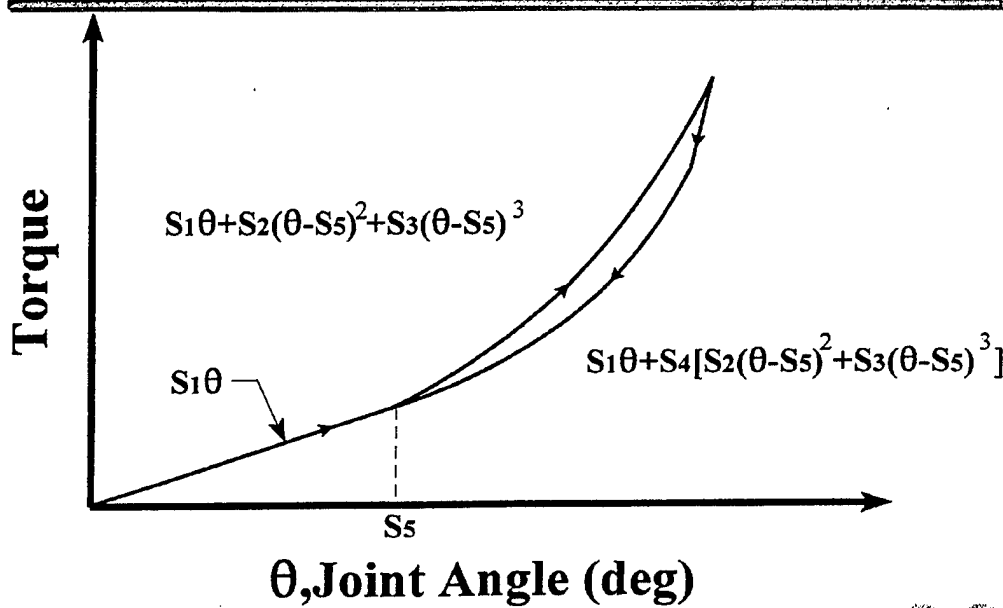


Figure 2. Joint Spring Torque Definition. From Ref. [4]

# Joint Torques

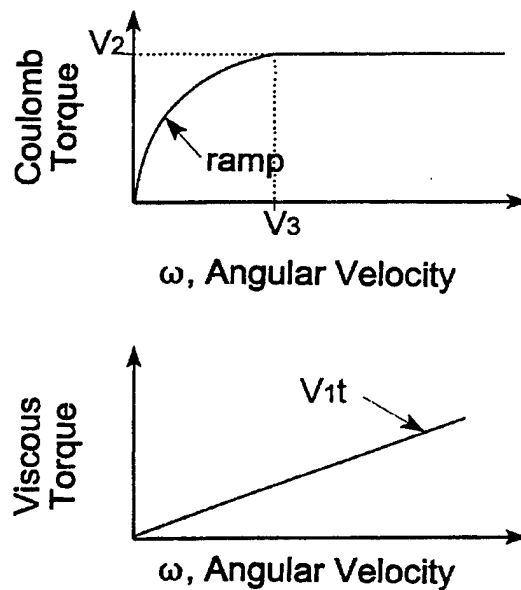


Figure 3. Joint Viscous and Coulomb Torque Definition. From Ref. [4]

### b. Representation of the environment

In the ATB program, the environment within which the body or bodies exist and interact is composed of contact planes, ellipsoids, and hyperellipsoids. Up to 30 contact planes and up to 40 contact (hyper) ellipsoids may be defined by the user to create the environment. These contact surfaces may be attached to one of up to six allowed vehicles for which motion is specified as described in the section concerning input excitation. Note that each vehicle counts as a segment, so the total number of segments allowed (30) is reduced by one for each specified vehicle.

Contact planes are specified by defining three points, P1, P2, and P3, which form the sides of a parallelogram as shown in Figure 4. Contact with a plane must occur from the positive side, the outward normal to which is defined by the cross product of edges P1-P2 and P1-P3 as shown. The points P1, P2, and P3 are defined by (x,y,z) values referenced to a designated coordinate system in a manner discussed in more detail in the section on creating an input deck.

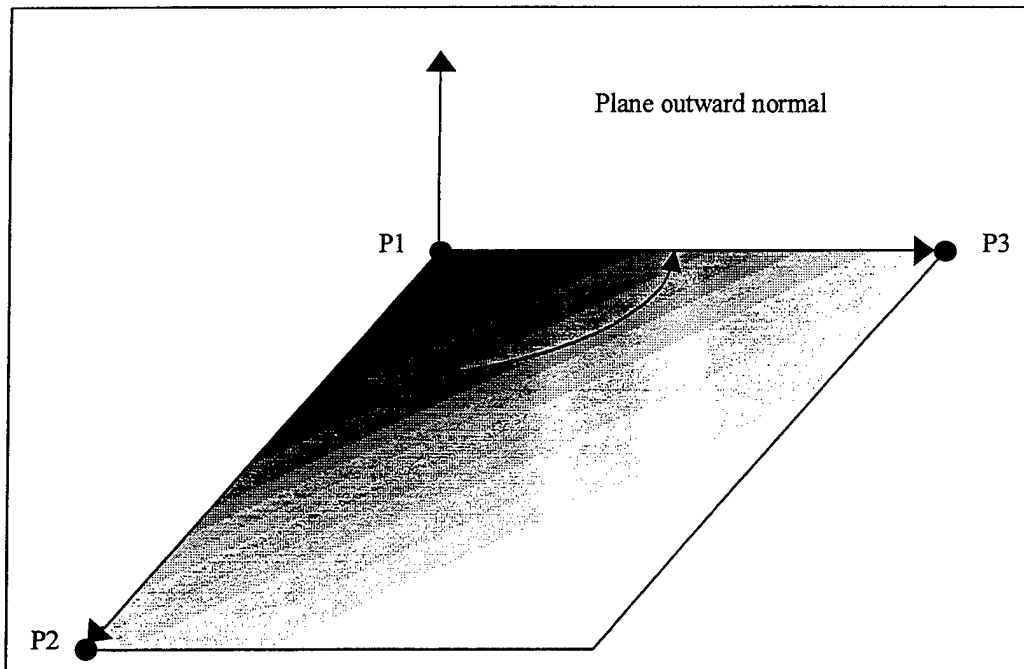
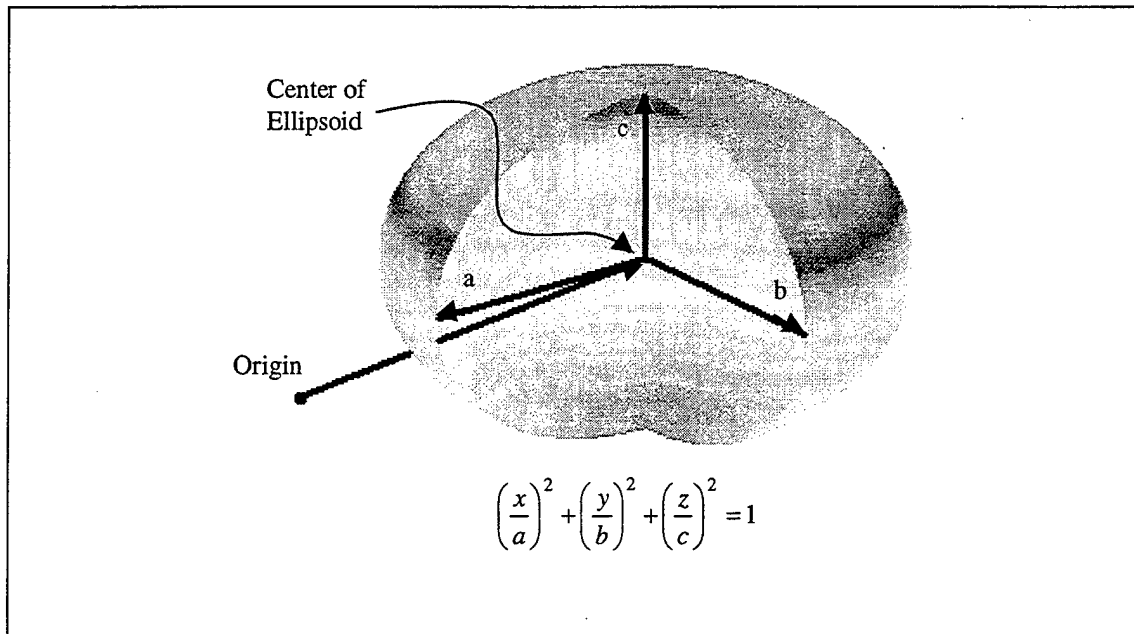
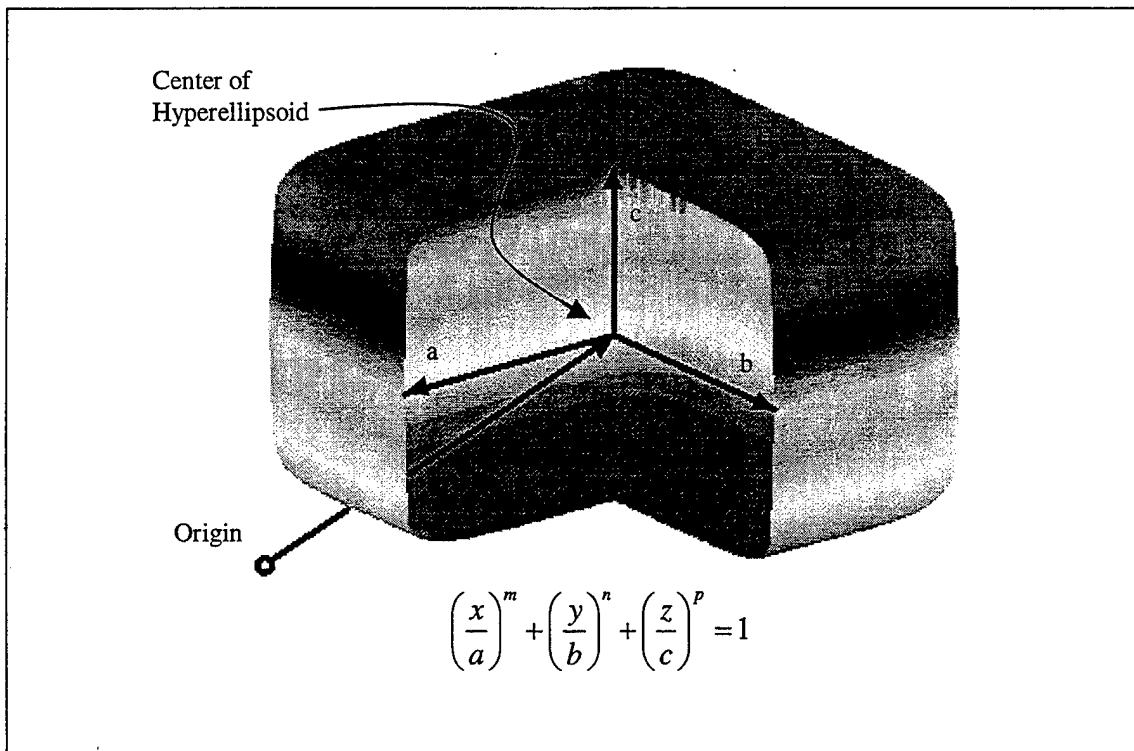


Figure 4. Plane Definition. After Ref. [4]

In a similar fashion, additional contact ellipsoids and hyperellipsoids may be defined by the user. Figure 5 shows an example ellipsoid and Figure 6 shows an example hyperellipsoid. These (hyper) ellipsoids are defined by specifying the center of the ellipsoid (in the reference frame of the segment with which they are associated), the lengths of the three semi-axes ( $a$ ,  $b$ , and  $c$ ), and, for hyperellipsoids, the powers ( $m$ ,  $n$ , and  $p$ ). For hyperellipsoids, the powers must all be even integers, and must all be the same.



**Figure 5. Ellipsoid Definition**



**Figure 6. Hyperellipsoid Definition.**

**c. Input excitation**

Excitation of the model is provided by prescribing the motion of the vehicle or vehicles to which the contact surfaces (planes, ellipsoids, or hyperellipsoids)

are attached. This motion may be prescribed in one of four basic manners: (1) Half-sine wave deceleration pulse, (2) Tabular unidirectional deceleration, (3) Six degree-of-freedom deceleration, or (4) Spline fit position, velocity or deceleration data. Deceleration, vice acceleration, pulses are used since the ATB program was originally developed to model the response of crash dummies, which typically experience decelerations upon impact.

Option 1, the half-sine wave deceleration pulse, is the easiest of the four options. The user simply specifies the initial velocity of the vehicle, the duration of the deceleration pulse, and the azimuth and elevation of the deceleration vector as shown in Figure 7.

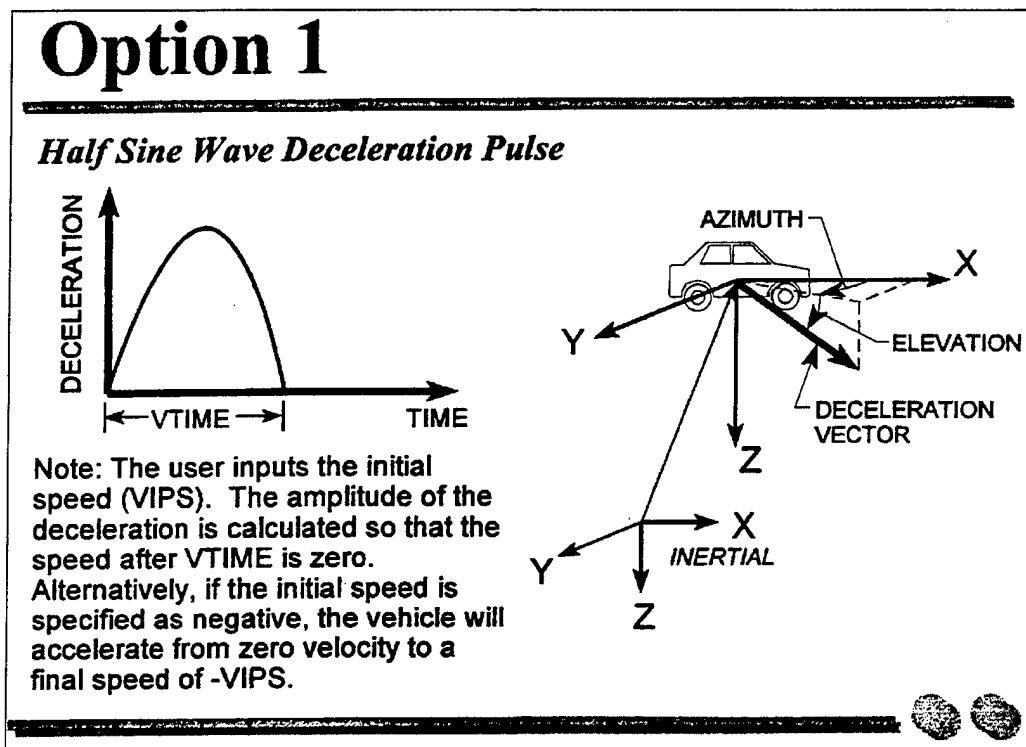


Figure 7. Half-sine Wave Deceleration Pulse Specification. From Ref. [4]

Option 2, the tabular unidirectional deceleration is also quite easy to specify. The user simply defines the initial velocity of the vehicle and the azimuth and elevation of the deceleration vector as for Option 1, but instead of specifying a duration, the user specifies a start time, time increment, and the tabulated values for deceleration at each time step as shown in Figure 8. Without modifications, the ATB program requires that there be an odd number of tabulated decelerations with a maximum of 99.

Option 3, the six degree-of-freedom deceleration, makes it simple to directly use recorded data from accelerometers as the input excitation to the ATB model. The user again specifies the initial velocity of the vehicle, but must also specify the initial roll, pitch, and yaw angles as shown in Figure 9. In addition, the user must specify the number of time points, the start time, and the time increment as for the tabulated unidirectional deceleration option. However, instead of specifying an azimuth and

elevation for the deceleration vector, the user must specify all components of the vector – the three linear and three angular deceleration components – at each time step as shown in Figure 10. Without modification, the ATB program limits the number to time steps to a maximum of 501.

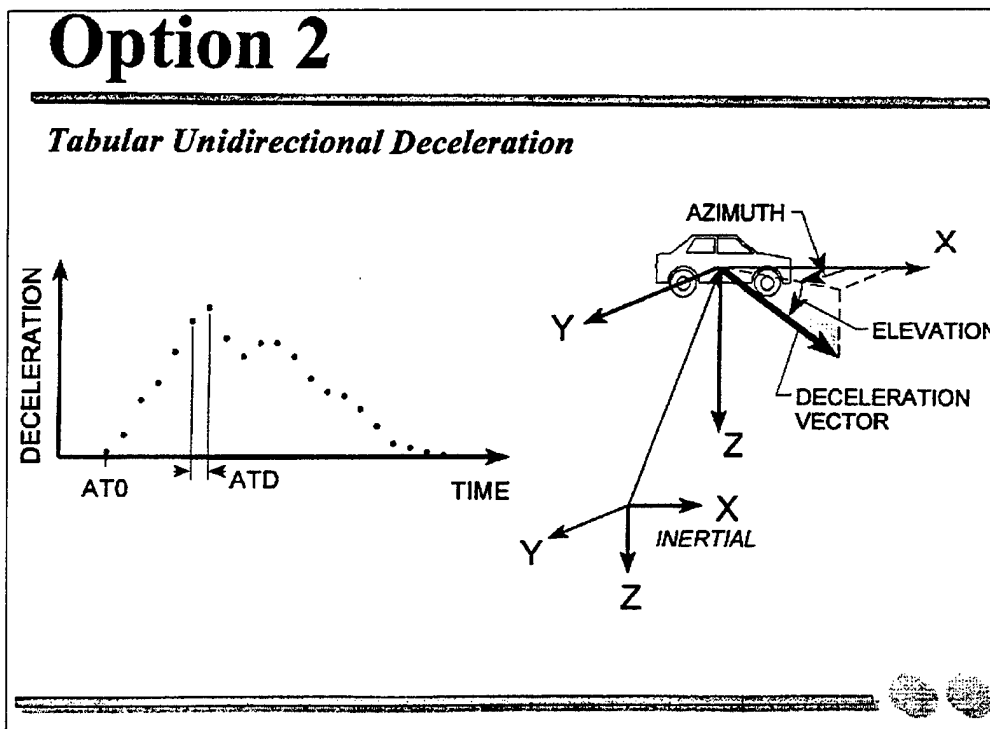


Figure 8. Tabular Unidirectional Deceleration Specification. From Ref. [4]

The final option, Option 4, the spline fit of position, velocity, or acceleration data, is the most general of the input methods. In this method, the user specifies the tabulated input data, in six degrees of freedom, as shown in Figure 11. The ATB program, without modifications, limits to 101 the maximum number of time points that may be specified. If velocity data is specified, then the initial position, as well as the initial roll, pitch and yaw, of the vehicle must be specified. If deceleration data is specified, then, in addition to the initial position information, the initial velocities, both linear and angular, must also be specified as shown in Figure 12.

From the preceding paragraphs, it is obvious that the ATB program imposes relatively strict limits on the quantity of tabulated data points that may be used as input. These limitations were imposed when the program was initially developed and reflected the limitations in available computing power. In order to simulate response to an underwater explosion event, it is generally necessary to have a relatively long time record sampled at a relatively high frequency to adequately capture the impulse-like peaks. This combination would typically yield far more data points than allowed by the ATB program. Fortunately, it is simple to modify the source code to increase the allowed number of data records.

## Option 3

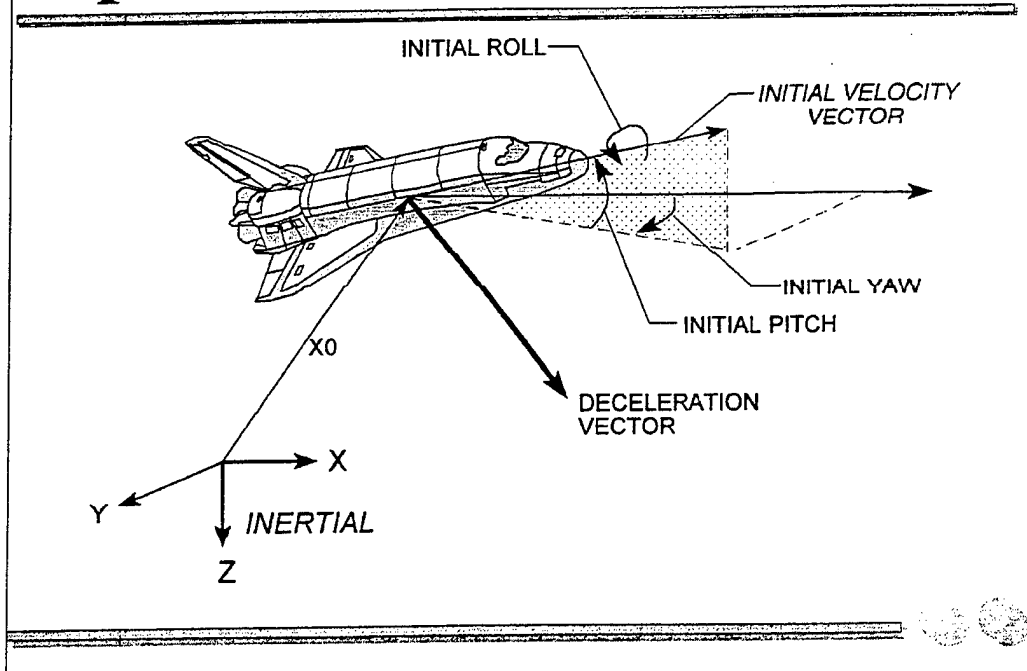


Figure 9. Six Degree-of-Freedom Deceleration Initial Conditions. From Ref. [4]

## Option 3

### *Six Degree of Freedom Deceleration*

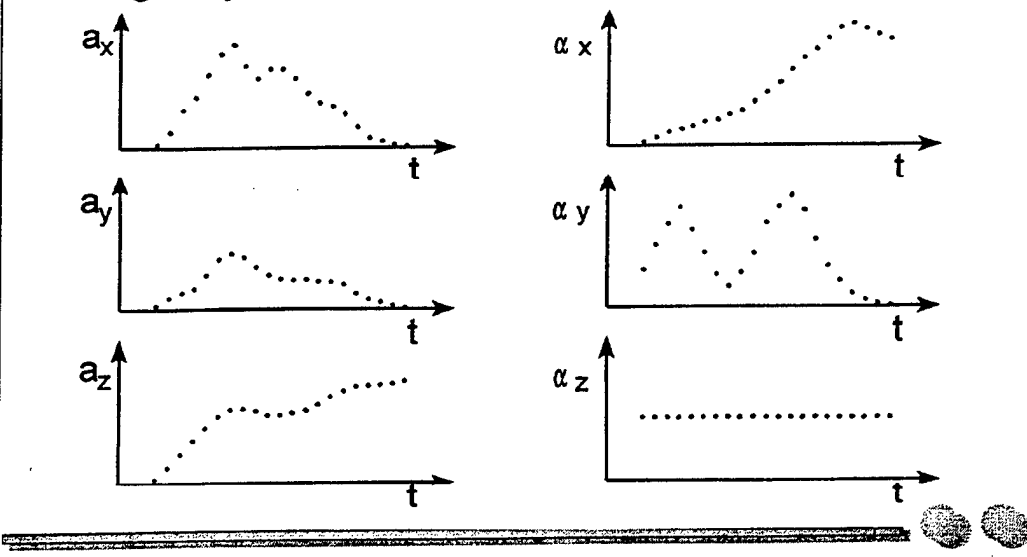


Figure 10. Six Degree-of-Freedom Deceleration Specification. From Ref. [4]



# Option 4

## Spline Fit Position, Velocity, or Deceleration

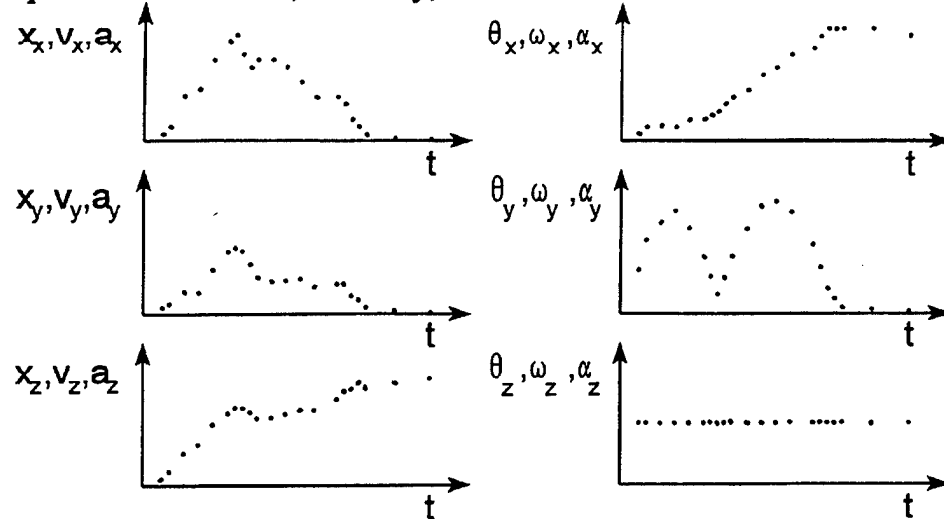


Figure 11. Spline Fit Specification. From Ref. [4]

# Option 4

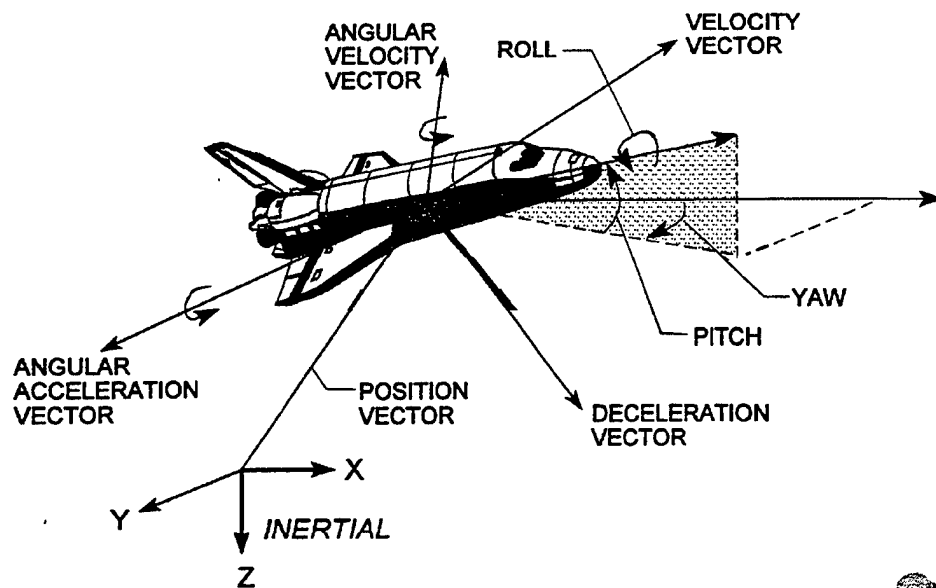


Figure 12. Spline Fit Initial Conditions. From Ref. [4]

#### **d. Interaction between bodies and the environment**

Forces are applied to the body segments by means of evaluating the penetration of the body segment ellipsoids into the contact surfaces, either planes or (hyper) ellipsoids, representing the environment. The motion of the body elements is then determined by solving Newton's equations of motion, including the compatibility relationships based on Newton's Third Law. For further reading on the manner in which the interaction between body segments and the environment is computed, consult Ref. [5].

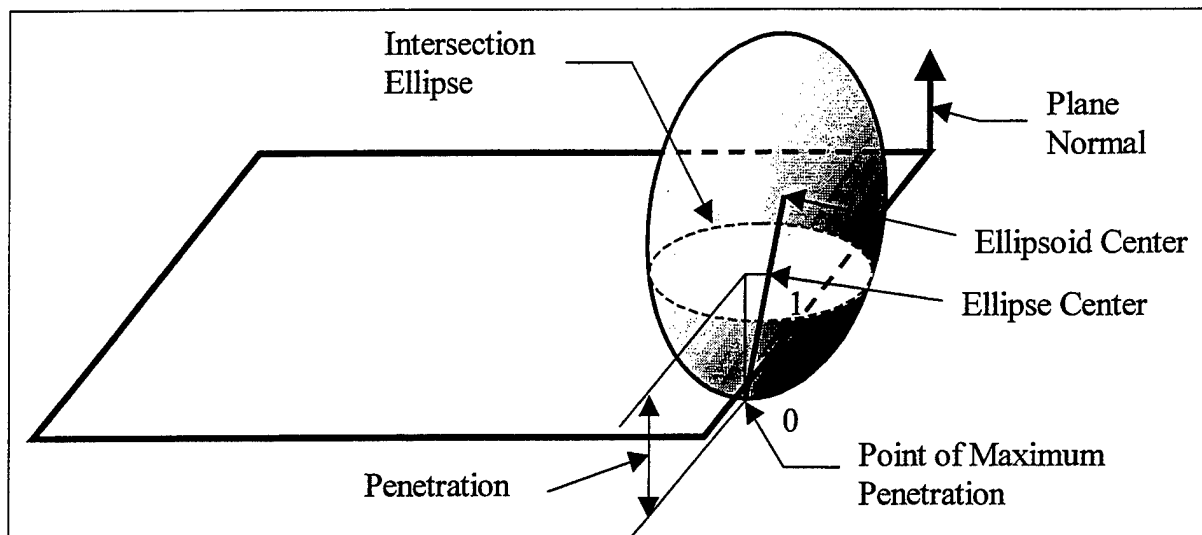
Figure 13 shows how a plane-segment contact is evaluated. The intersection of the ellipsoid with the plane forms an ellipse. The perpendicular distance from the plane to the point of maximum penetration of the ellipsoid is defined to be the penetration (or deflection). This value is used in the force-deflection formulas to compute the force resulting from the contact. The computed force is then applied, normal to the plane, to a point along the line between the center of the ellipse formed by the ellipsoid-plane intersection and the point of maximum penetration. The point at which the force is applied is set by the user through the specification of a parameter, D4, that ranges from 0 – force applied at point of maximum penetration, to 1 – force applied at center of the intersection area. If the segment is harder than the plane, e.g., head contact with seat cushion, then the force should be applied closer to the point of maximum penetration (D4 closer to 0). If the segment is softer than the plane, e.g., abdomen contact with a table surface, then the force should be applied closer to the center of the intersection area (D4 closer to 1) [Ref. 5].

Another parameter governs how plane-segment contacts are evaluated when the intersecting ellipse does not lie fully within the boundaries of the plane as shown in Figure 13. The plane can be assumed to be infinite, thus no check is made to see if the intersecting ellipse lies fully within the plane, or the plane can be assumed to be finite, thus an edge check is performed. If an edge check is specified, the user must then specify whether a force is applied when the center of the intersecting ellipse does not lie within the boundaries of the plane. If the user does desire a force to be applied in this case, then the deflection and corresponding force are computed based on the centroid of the area of the ellipse that lies within the boundaries of the plane [Ref. 1]. For either infinite or finite planes, the user may also specify whether a force is applied for complete penetration of the ellipsoid. The ATB program limits the number of plane-segment contacts to five per plane, with a maximum of 70 total plane-segment contacts. Duplicate planes may be added if more than five segments are expected to contact the surface in question.

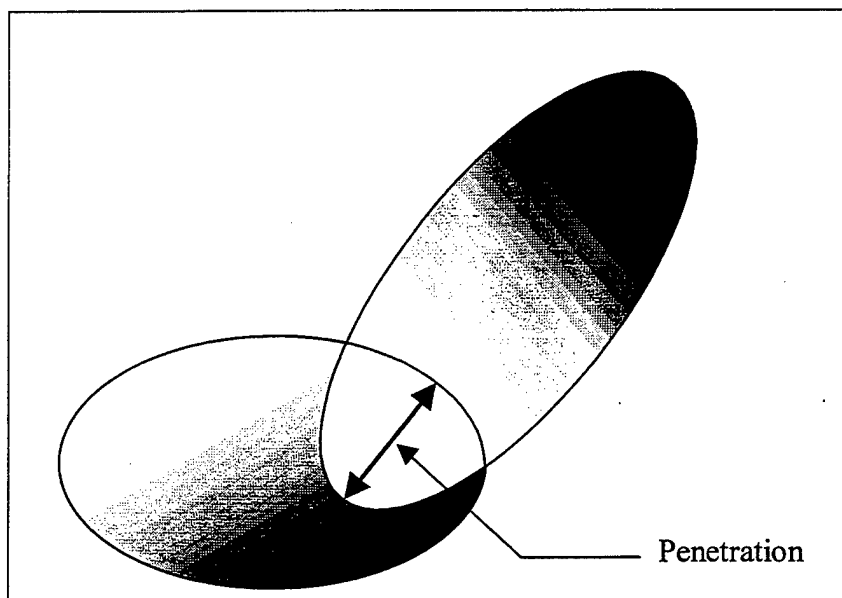
Evaluation of segment to segment contacts is significantly simpler than evaluation of segment to plane contacts as can be seen in Figure 14. There are no edge effect or point of application decisions to be made, just the force-deflection characteristics, as described in the following paragraph. The ATB program limits the number of segment-segment contacts to five per segment, with a maximum of 40 total segment-segment contacts.

Force-deflection characteristics must be defined for each allowed contact, either between segments and planes or segments and other segments. In each case, the characteristics are defined by five parameters or functions (plus the edge effect parameter

in the case of plane-segment contacts). These five functions are used to define force-deflection characteristics that are either rate dependent or have inertial spike, permanent deformation, and energy absorption properties.



**Figure 13. Plane-Segment Contact Definition. After Ref. [4]**



**Figure 14. Segment-Segment Contact Definition. After Ref. [4]**

If rate dependent force-deflection characteristics are desired, then four functions,  $f_1$  through  $f_4$  as shown in Figure 15, plus a friction coefficient, are defined. Each of the individual functions that make up the overall force-deflection characteristic is defined as shown in Figure 16. The lower and upper abscissa values for the each part of the function ( $D_0$ ,  $D_1$ , and  $D_2$ ) are defined, then, the function components themselves ( $F_1$  and  $F_2$ ) are defined in either tabular or polynomial form, or, for  $F_1$ , as a constant. The

allowed combinations are summarized in Table 1. So, for each portion of the rate dependent force-deflection characteristic definition (f1 through f4 as shown in Figure 15), an entire function must be specified (created as shown in Figure 16 and Table 1). The ATB program limits the number of individual functions to 50.

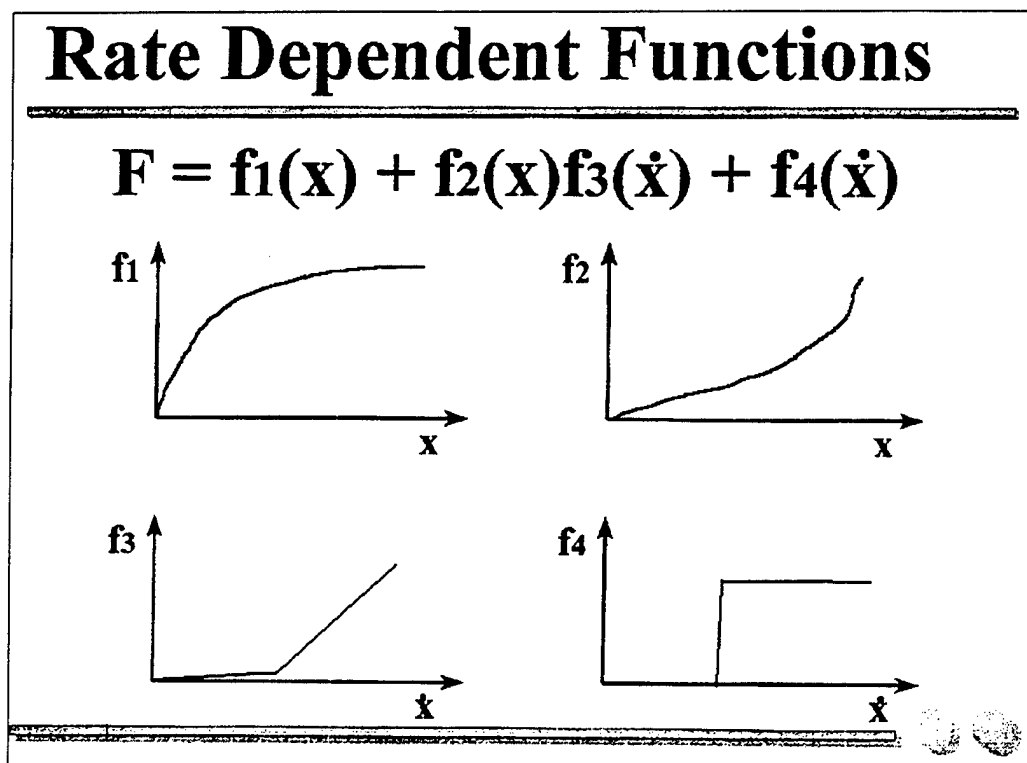


Figure 15. Rate Dependent Functions. From Ref. [4]

Table 1. Function Subdivision Definitions. After Ref. [1]

FUNCTION COMPONENT		ABSCISSA VALUE		
F1	F2	D0	D1	D2
Constant	--	0	0	D2 = F1
Tabular	--	D0	D1 < 0	0
Polynomial	--	D0	D1 > 0	0
Tabular	Polynomial	D0	D1 < 0	D2 > 0
Polynomial	Tabular	D0	D1 > 0	D2 < 0
Polynomial	Polynomial	D0	D1 > 0	D2 > 0

If rate dependent functions are not desired, but it is desired to specify inertial spike, permanent deformation and/or energy absorption properties based solely upon the deflection, then the force-deflection characteristics are defined as shown in Figure 17. The individual functions for the base, inertial spike, energy absorption factor, and permanent deformation factor components of the force-deflection characteristic are each defined as described in the above paragraph.

## Function Subdivisions

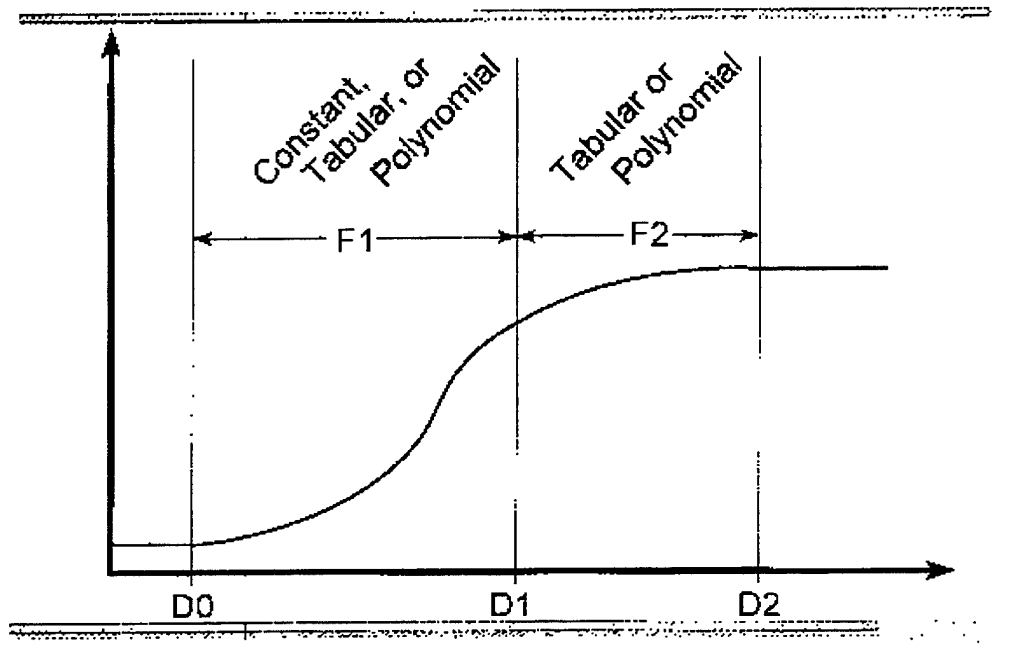


Figure 16. Function Subdivisions. From Ref. [4]

## Functions

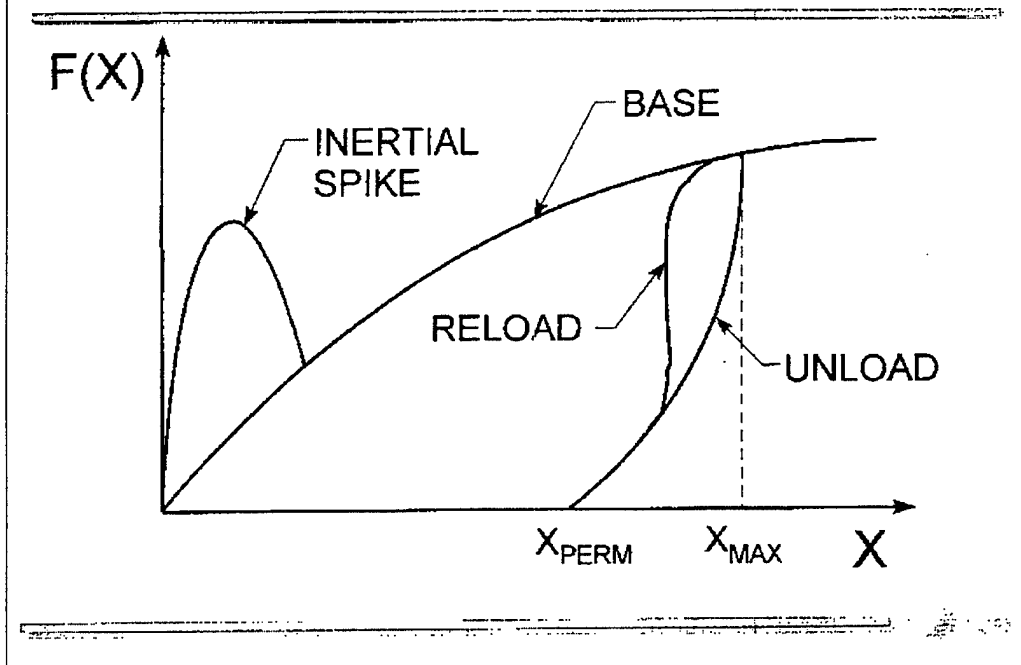
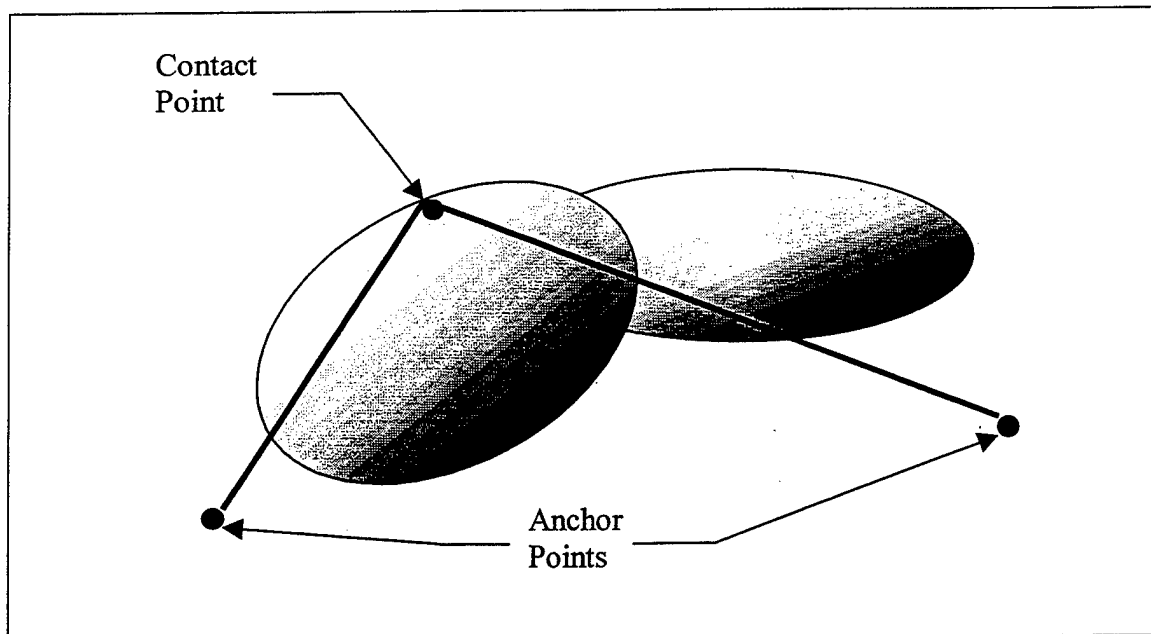


Figure 17. Alternate Function Definition. From Ref. [4]

#### e. Simple and harness belts

The ATB program allows for the incorporation of up to eight simple belts and/ or up to five harness belt systems into the model. These belts are commonly used to model seat belts in cars or ejection seat harnesses in aircraft.

Simple belts are defined by two anchor points and a single fixed contact point on a body segment as shown in Figure 18. It is required that the anchor points do not coincide (if they are physically the same point, they must be defined slightly separated) since the ATB program defines a plane using the two anchor points and the fixed segment contact point [Ref. 1]. Belt-segment contact forces (a maximum of one segment may contact each simple belt) are evaluated in a manner similar to plane-segment forces. The force-deflection characteristic functions are also defined in the same manner, although rate dependent functions are not permitted and the abscissa is in terms of strain (in/in) vice deflection. The friction force between the belt and a contacting segment is either full friction (forces computed separately for each half of the belt) or no friction (belt tension is the same throughout the belt). In addition to the force-deflection characteristics for the simple belts, an initial slack may be specified. The belt length is specified to be the sum of the distances between the anchor points and the fixed contact point on the plus the initial slack. Belt pre-tensioning is not allowed and the specification of a negative initial slack has the same result as specifying an initial slack of zero.



**Figure 18. Simple Belt Illustration. After Ref. [4]**

Harness belts are significantly different from simple belts and provide the user much more control over the construction of the belt system and the interaction between the belts and body segments. As stated earlier, a maximum of five harness belt systems may be defined. Each such system may have one or more belts, but the total number of belts in all harness belt systems must be no greater than 20. For each belt, force-deflection characteristics and initial slack are defined as for the simple belt, but the

harness belt option allows for the use of rate dependent functions and pre-tensioning by specification of a negative initial slack. In addition, the characteristics are defined for the contact between the belt and the segment at each reference point described in the following paragraph.

For each belt in a harness belt system, the user must define anchor points and reference points, as shown in, for up to a maximum of 50 for any one harness belt system and 100 for all harness belt systems combined. The anchor points may be fixed or allowed to move with a force-deflection characteristic defined in the same manner as for each reference point. The reference points are the user specified contact points along the path of the belt and may be associated with one or more segments, as shown in Figure 19. For each reference point, in addition to the normal force-deflection characteristics (rate dependence is permitted), the user may specify a preferred direction for the reference point to move along the surface of the segment, or the user may allow the belt to slip along the nominal belt line. If the function  $f_1$  (base function as shown in Figure 17 or  $F_1(x)$  as shown in Figure 15 for rate dependent characteristics) is given as zero, then the surface of the segment is treated as rigid and the belt is not allowed to move normal to the surface. If the forces computed are such that they would tend to pull the belt away from the surface of the segment, then the reference point is dropped as shown in Figure 19 unless it is specified to be an anchor or tie point. When the friction coefficient is defined for the belt-segment contact, a value must be specified for motion along the belt line tangent and a separate value specified for motion along the belt line normal. See Ref. [1] for further details on options regarding harness belts.

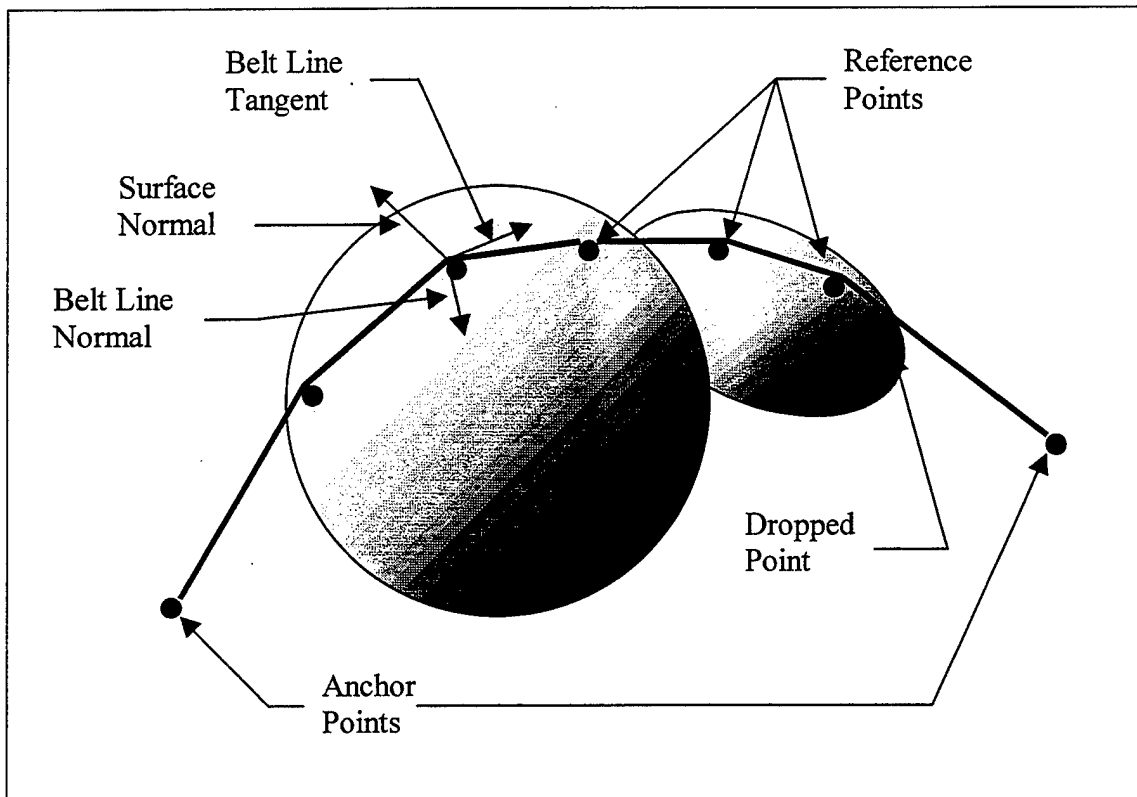
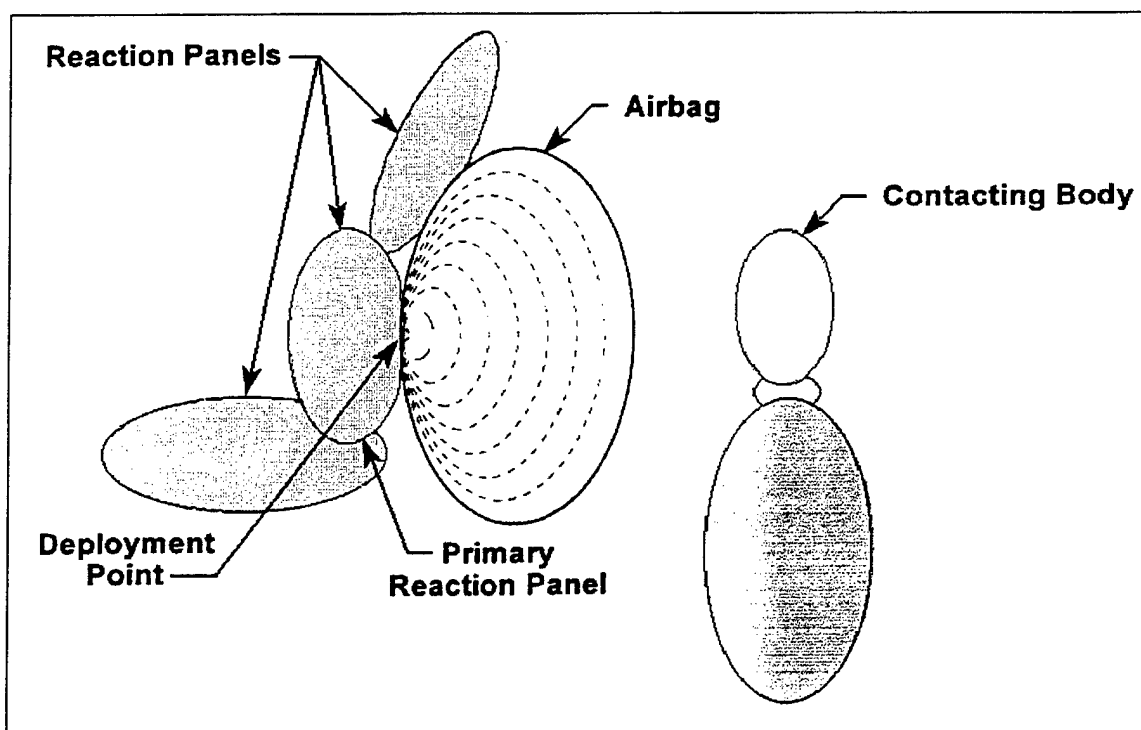


Figure 19. Harness Belt Illustration. After Ref. [4]

#### **f. Miscellaneous features**

There are several additional features of the ATB program, including airbags, wind forces, spring-dampers and applied forces or torques.

A maximum of five airbags can be defined, but the total number of segments, vehicles, and airbags must be less than 30. A sample airbag setup is shown in Figure 20. Up to four reaction panels (ellipsoids defined by their center, semi-axis lengths, and angular orientation with respect to the vehicle) may be defined for each airbag in order to model the surfaces in the vehicle with which the airbag would interact. The first such panel to be defined is the primary reaction panel and the deployment point of the airbag is defined on this panel. The size and location of the fully deployed, but undeformed, airbag contact ellipsoid are specified by the location of the center of the ellipsoid and the three semi-axis lengths. In addition, the user must specify the appropriate gas dynamics properties (temperature, pressure, ratio of specific heats, gas constant, sonic throat area and discharge coefficient, etc.) for each specified airbag. See Ref. [1] for further details on airbags.



**Figure 20. Airbag Setup. After Ref. [4]**

Wind forces may be applied to segments as shown in Figure 21. A wind plane is specified such that aerodynamic forces are applied to a segment (which must be identified as a segment for which wind force calculations are to be performed) only if it passes through the plane. Wind pressure and drag forces may be specified and their functions are defined in a similar manner as the individual functions making up the force-deflection characteristics. For the wind pressure force, a time dependent force may be defined in exactly the same manner as an individual function for force-deflection



characteristics. Or, alternatively, a wind force function may be defined that computes the force based on the relative velocity of the segment in question using a subsonic, inviscid, compressible flow formulation with user specified fluid properties. In either case, the drag force is computed as from a user specified drag coefficient multiplied by the wind pressure force. See Ref. [1] for further details on wind forces.

Up to 20 spring-damper combinations may also be specified. Each spring-damper is defined, as shown in Figure 22, by the points of connection on two specified segments and by specifying the force-deflection/force-rate of deflection properties. The spring and damper are both represented by quadratic functions and specified by the initial length of the spring and two coefficients for each. Equation (1) shows the function used to compute the applied force for the spring.  $D$  is the distance between points APSDM and APSDN as shown in Figure 22,  $D_0$  is the initial length,  $A1$  is the linear spring constant (lb/in), and  $A2$  is the quadratic spring constant (lb/in<sup>2</sup>). If  $A1$  is defined as negative, then the spring-damper will act as a tension element only and for  $(D - D_0) < 0$ , no forces will be applied. Equation (2) shows the function used to compute the applied force for the damper.  $DV$  is the time derivative of the value  $D$ ,  $B1$  is the linear damping coefficient (lb sec/in), and  $B2$  is the quadratic damping coefficient (lb sec<sup>2</sup>/in<sup>2</sup>). See Ref. [1] for further details on spring-dampers.

$$F_s = (D - D_0) * (|A1| + A2 * |D - D_0|) \quad (1)$$

$$F_d = DV * (B1 + B2 * |DV|) \quad (2)$$

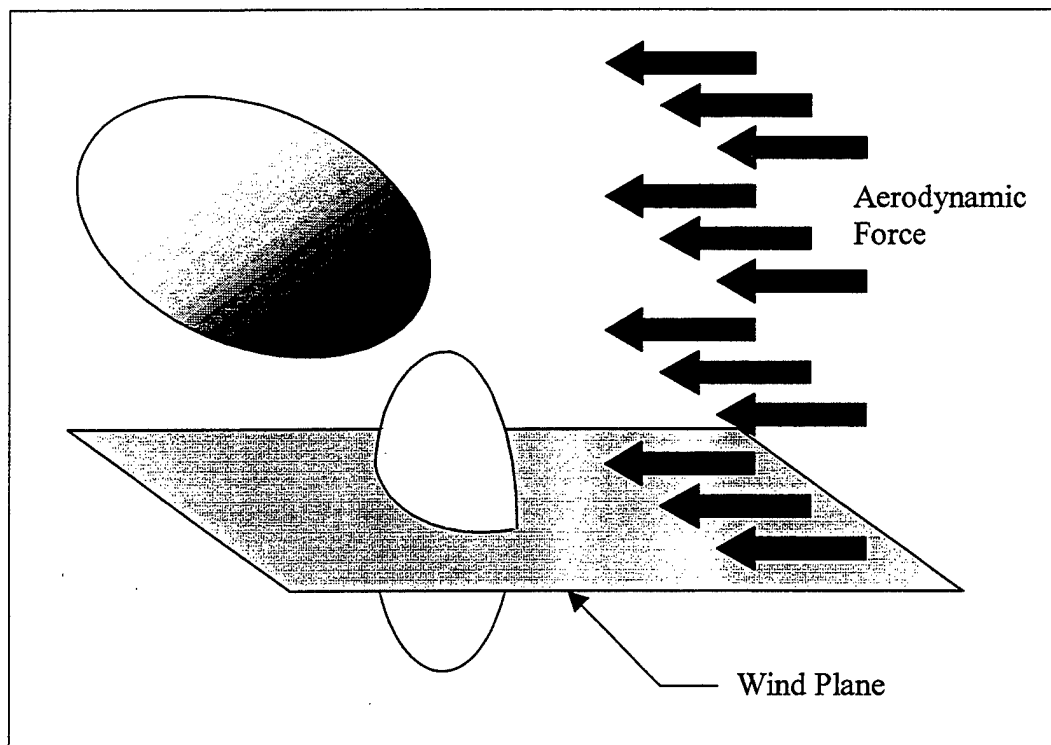


Figure 21. Wind Force Illustration. After Ref. [4]

Up to five time dependent forces or torques can be applied to user specified segments. Each force (torque) is defined by a function, the point of application is defined by (x,y,z) coordinates in the local reference system of the segment, and the direction vector is defined by yaw, pitch, and roll angles with respect to the segment's local axes. See Ref. [1] for further details on applied forces and torques.

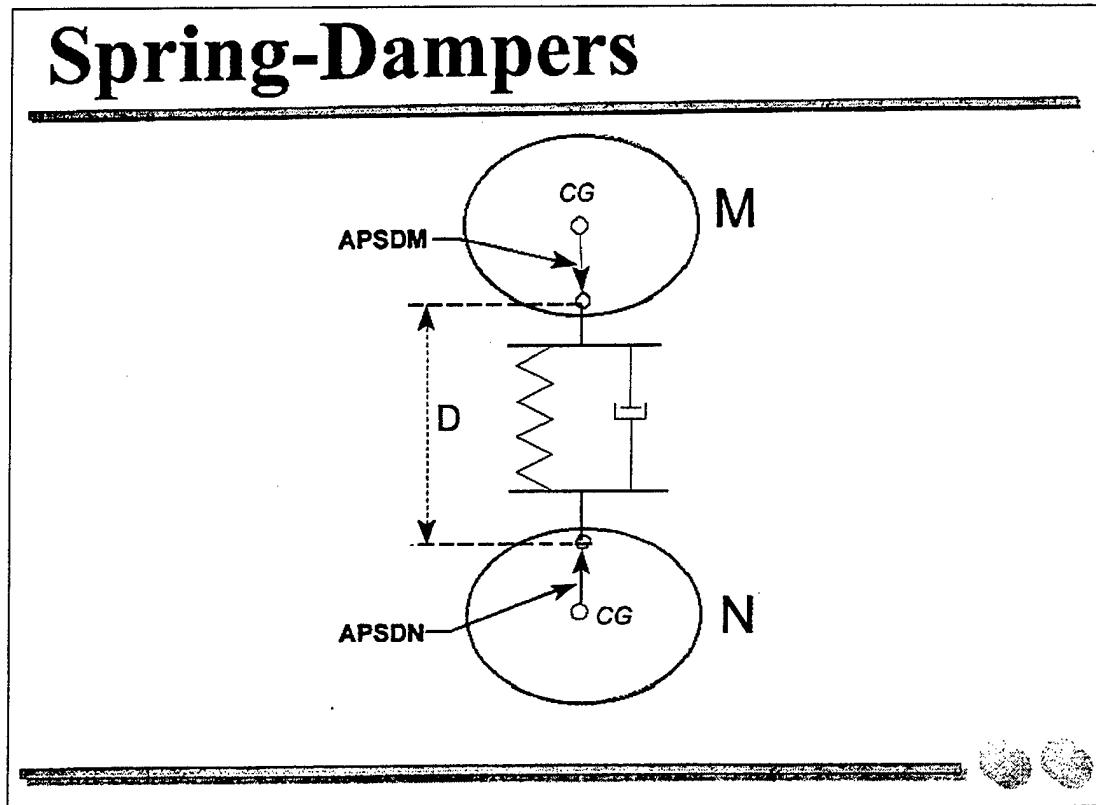


Figure 22. Spring-Damper Illustration. From Ref. [4]

## 2. File Structure.

The ATB program requires a single primary input file and can produce several output files. Each type of file is associated with the same filename, but with different extensions based on the kind of file in question. The ATB program file structure and interconnections are illustrated in Figure 23. The terminology used with the ATB program results from its development, using the FORTRAN programming language, in the early 1970's and the fact that punch cards were used for input. The input file (\*.AIN) is frequently referred to as the input deck and the individual lines of this file are referred to as cards. The output files have extensions \*.TP# or \*.T##, abbreviations for tape.

### a. Input deck

The input file, or deck, to the ATB program contains all the necessary information to build models of bodies and vehicles, to apply excitation to one or more of the vehicles, and to specify what data output is desired. This information is structured in 80 column lines of formatted alphanumeric data, each of which is referred to as a card.

Cards containing related information are collected into groups and are referred to as A Cards, B Cards, etc. Table 2 provides an outline correlating the card groups and the information contained within each. The format for each individual card is explicitly defined in Ref. [1].

Since there are so many different options available within the ATB program, not all cards are required for every situation. The information contained within one card may dictate that other cards must be included, and still others are not required. In the following chapter, the construction of an input file is discussed in detail.

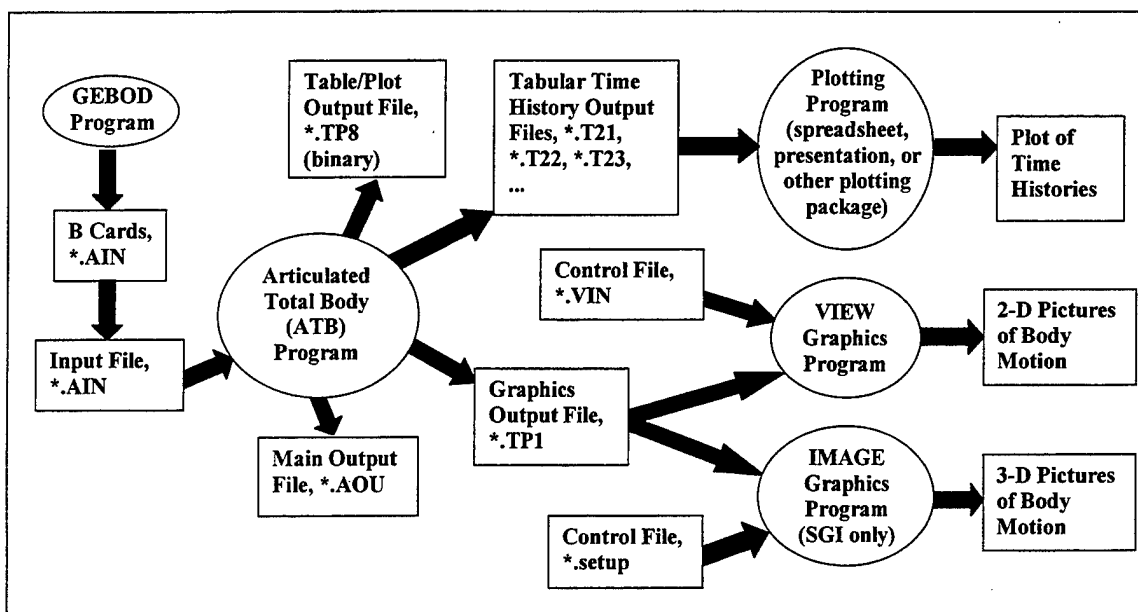


Figure 23. ATB Program File Structure. After Ref. [4]

### b. Output options

The ATB program allows the user to specify nearly any combination of a variety of output options. The main output file from the ATB program (\*.AOU) produces a completely annotated reproduction of all of the data in the input file, as well as some data concerning the amount of central processing unit (CPU) time used by the major subroutines in the program. Another output file (\*.TP1) can be generated for use with the VIEW and/or IMAGE programs to provide 2- or 3-dimensional graphical representation of the model. A third output file (\*.TP8) can be generated for use with postprocessors included within the ATB program for the computation of Head Injury Criteria (HIC), Head Severity Index (HSI), and Chest Severity Index (CSI), which are all measures of the severity of an injury and will be discussed in greater detail later.

**Table 2. Outline of ATB Input Deck. After Ref. [1]**

<b>Card Group</b>	<b>Information Contained</b>
A	Date and run description, units of input and output, control of restart, integrator and optional output.
B	Physical characteristics of the segments and joints.
C	Description of the vehicle motion.
D	Contact planes, belts, air bags, contact (hyper) ellipsoids, constraints, symmetry options, spring dampers, and prescribed forces and torques.
E	Functions defining force-deflections, inertial spike, energy absorption factor, and friction coefficients.
F	Allowed contacts among segments, planes, belts, airbags, contact (hyper) ellipsoids and harnesses.
G	Initial orientations and velocities of the segments
H	Control of output of time history of selected segment motions, joint parameters, wind forces, joint forces and torques, total body properties, and injury criteria.
I	Control information for plotter output.

The user may also specify, using a single parameter, to have time histories generated for nearly any combination (see Ref. [1] for allowed combinations) from the following list:

1. Plane-segment contact forces.
2. Belt-segment contact forces.
3. Harness belt forces.
4. Spring-damper forces.
5. Segment-segment contact forces.
6. Airbag contact forces.

Perhaps the most common selections would be plane-segment and segment-segment contact forces. For the plane-segment contact forces, the deflection, normal, friction and resultant forces, and the location of the contact in the coordinate system of the segment to which the plane is attached are tabulated at a frequency specified by the user. A separate file is generated for each two plane-segment contacts allowed. For the segment-segment contact forces, the deflection and normal, friction, and resultant forces are tabulated just as in the plane-segment contact case, but the location is now specified in the reference coordinates of each of the contacting segments, again at the frequency specified by the user. In contrast to the plane-segment contact option, a separate file is generated for every single allowed segment-segment contact. All tabulated time history output files are sequentially numbered beginning with \*.T21.

In addition to the above options, which provide tabulated output for each allowed contact or force, the user may specify a total of up to 20 individual tabulated time histories from the following list:

1. Linear acceleration, velocity or displacement of a segment.
2. Angular acceleration, velocity or displacement of a segment.

### 3. Angles and torques for a joint.

For the linear and angular accelerations, velocities, and displacements, the tabulated output includes the x, y, and z components of the quantity, as well as the resultant, in the user specified coordinate system. In addition, the quantities can be computed at the center of gravity of the segment, or at any point offset from the center of gravity, allowing more flexibility for the user. For the joint parameters, the angles of flexion, azimuth, and torsion, as well as the spring, viscous, and total torques, are tabulated.

The user may also elect to have a tabulation of wind forces or to have printer plots generated. See Ref. [1] for further details on tabulated time history options.

For a typical run, many output files can be generated. If the user elects to specify the outputs to be tabulated at frequent intervals (e.g. to allow for easy comparison with recorded accelerometer data for a model validation), then these files can become quite large. For example, a plane-segment contact file generated at 1 msec intervals for a 2 second simulation (2000 lines) will require approximately 250 KB of disk space, which, if there are 40 similar size files, equates to roughly 10 MB of disk space. This figure does not include the individual files for use with the VIEW/IMAGE programs or with the ATB program's post-processing routines. Another point of concern is the total number of files open at one time. When the ATB program is started, it creates/opens all of the required output files and keeps them open, writing data to each file as it is computed, until the completion of the simulation. Use of a compiler such as Microsoft's FORTRAN Visual Workbench Version 1.00 limits the number of files which may be open at one time to 61. If more output files are required when working in such an environment, then multiple runs of the simulation may be required with different selections (e.g., run with plane-segment contacts only tabulated, then run a second time with segment-segment contacts only tabulated). Other environments may not impose this restriction, or may have different restrictions.

## B. GENERATOR OF BODY DATA (GEBOD) PROGRAM

In order to use the ATB program to model the biodynamic response of anthropomorphic test devices (ATD's) or human beings, one must first determine an accurate representation of the ATD or human being as a series of individual rigid segments connected by various kinds of joints. It is for this reason that the GEBOD program was developed [Ref. 2].

### 1. Program Overview

The GEBOD program is used to provide the input data sets for use with the ATB program for modeling ATD's or human beings. Each input data set includes the geometric and mass properties of the body segments as well as the locations and mechanical properties of the joints connecting the body segments. The program is written in FORTRAN 77 and may be run on a personal computer either in DOS or from a DOS window in a Windows environment.

#### **a. Modeling options**

The GEBOD program may be used to generate ATB input data for the following types of subjects [Ref. 2]:

1. Child (2-19 years of age)
2. Adult human female
3. Adult human male
4. User-supplied body dimensions
5. Seated Hybrid III Dummy (50<sup>th</sup> percentile)
6. Standing Hybrid III Dummy (50<sup>th</sup> percentile)
7. Hybrid II Dummy (50<sup>th</sup> percentile)

Upon starting the program, the user must input a description of the subject to be modeled and an output filename. Then, the user must choose one of the above options to specify the type of subject to be modeled and, depending upon the choice, may have to specify further information.

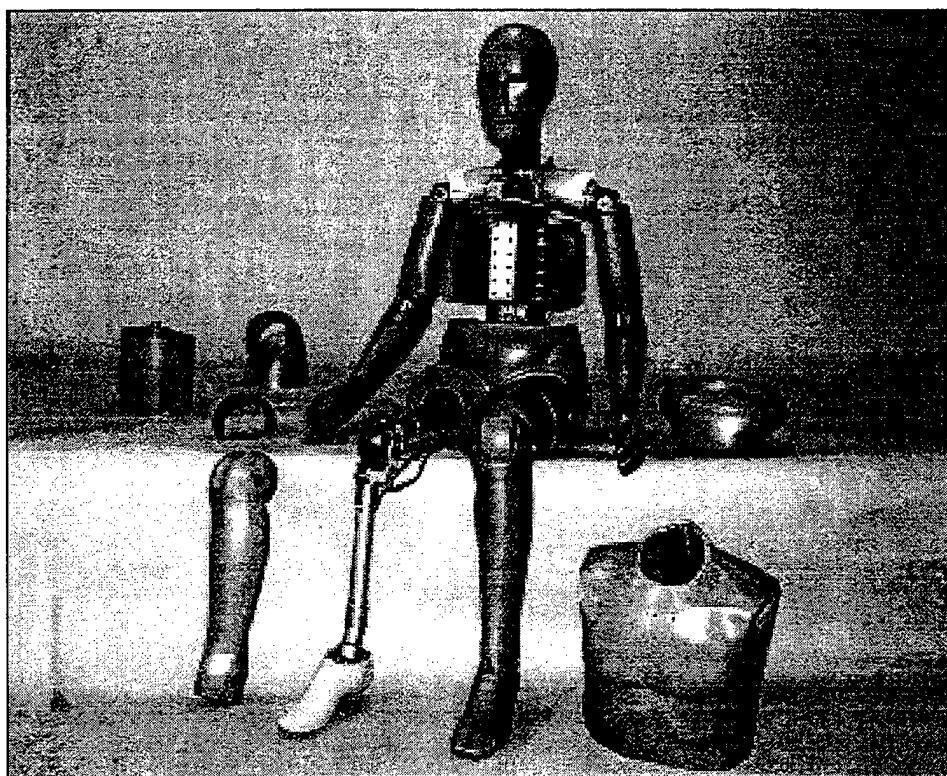
For the child, the user must decide if the data set is to be based upon the child's age, weight, height, or all three, and, depending upon the selection, the user must then provide the appropriate information. For the adult human male and female options, the user decide if the data set is to be based upon the subject's weight, height, or both, and, again, must specify the appropriate information. For the adult humans, the user may elect to specify the weight and/or height in terms of percentile rather than specific quantities. Additionally, the user may elect to have the hand and forearm modeled as a single segment, producing a 15-segment body, or as individual segments, producing a 17-segment body.

If the user elects to supply body dimensions, thus allowing the generation of a more specific body configuration than based solely upon weight and/or height, the dimensions shown in Table 3 must be defined. For a detailed description of each of the required dimensions, consult Ref. [2].

The GEBOD program allows the user to generate the body data sets for three ATD's – the Hybrid II Dummy (50<sup>th</sup> percentile male), and the Hybrid III Dummy (50<sup>th</sup> percentile male) with either the standing pelvis or the seated pelvis. The Hybrid II Dummy was developed in the early 1970's by the General Motors Corporation in order to assess the integrity of automobile lap/shoulder belt systems and has been widely used in motor vehicle and aviation safety standards tests [Ref. 6]. The Hybrid III Dummy was developed in the mid 1970's, also by the General Motors Corporation, has improved impact response biofidelity of the head, neck, chest and knees, and is used worldwide [Ref. 6]. Figure 24 shows a Hybrid III Dummy partially disassembled to reveal some of the internal structure.

**Table 3. Body Dimensions. After Ref. [2]**

#	Dimension	#	Dimension
0	Weight	16	Hip Breadth, Standing
1	Standing Height	17	Shoulder to Elbow Length
2	Shoulder Height	18	Forearm-Hand Length
3	Armpit Height	19	Biceps Circumference
4	Waist Height	20	Elbow Circumference
5	Seated Height	21	Forearm Circumference
6	Head Length	22	Waist Circumference
7	Head Breadth	23	Knee Height, Seated
8	Head to Chin Height	24	Thigh Circumference
9	Neck Circumference	25	Upper Leg Circumference
10	Shoulder Breadth	26	Knee Circumference
11	Chest Depth	27	Calf Circumference
12	Chest Breadth	28	Ankle Circumference
13	Waist Depth	29	Ankle Height, Outside
14	Waist Breadth	30	Foot Breadth
15	Buttock Depth	31	Foot Length



**Figure 24. Hybrid III Dummy (50<sup>th</sup> Percentile Male). From Ref. [7]**

### **b. Source of model data**

The data used by the GEBOD program to generate the body segment and joint properties comes from a variety of sources. According to Ref. [2], the Hybrid II dummy data set was developed by Fleck, et. al., [see Ref. 8], and the Hybrid III dummy data sets were developed by Kaleps, et. al., [see Ref. 9]. For the humans, the body data sets are generated from four independent groups of regression equations: Body measurements, joint locations, segment volumes for mass calculations, and segment principal moments of inertia. These regression equations are first order linear equations with height and/or weight as independent variables (age is also an independent variable for the child body data sets) and were computed from body measurement survey data or stereophotometric data [Ref. 2]. For a far more detailed description of the process of converting survey data in to body data sets, see Ref. [2].

## **2. File Structure**

The GEBOD program requires no input file, unless the user-supplied body dimensions option is selected. In that case, the user is prompted for the filename (including the extension) of the input file containing the body dimensions. This input file must be formatted as four rows of eight numbers with field lengths of ten and the dimensions must be specified in the order shown in Table 3. The GEBOD program will produce tabulated output file (\*.TAB) and, if the user so desires, will produce another file (\*.AIN) in the proper format for inclusion in the input file to the ATB program.

### **a. \*.TAB output file**

The \*.TAB output file is always produced by the GEBOD program. It contains fully annotated listings and tabulations of the generated body data set. If the generated subject was a human, the dimensions of the body, as listed in Table 3 are included, along with segment and joint data. For each segment, the principal moments of inertia, the orientation of the principal axes, and the contact segment semi-axis lengths and location of its center are provided. For each joint, the location of the center and orientation of the axes (in the reference of each of the segments involved), the flexural and torsional spring characteristics, and the viscous characteristics are all provided.

If the generated subject was an ATD, the \*.TAB file contains the same data as for the humans, excluding the dimensions of the body, as well as some more detailed information. Force-deflection characteristics for the head surface, back of shoulder, chest, anterior pelvis, posterior pelvis, upper arm, forearm, hand, upper leg, knee, front of lower leg, back of lower leg, and foot are provided. Joint restoring forces are also provided for the right and left shoulder and hip joints, the lumbar spine, and the head and neck pivots.

### **b. \*.AIN output file**

If the user desires, the GEBOD program will produce an output file (\*.AIN) with the generated body data set already in the proper format for the ATB input file. This allows the user to simply insert the information directly into the input file without having to format or transcribe any data. If the generated subject was a human, the \*.AIN file will contain the segment and joint information on the B cards. If the generated subject was an ATD, the \*.AIN file will contain not only the B cards, but also



some D, E, and F cards containing the force-deflection and joint restoring force information described in the section above. The user must be careful when inserting this information into the input file for the ATB program as each group of cards (B, D, E, and F) are spread out throughout the input file.

### **C. VIEW PROGRAM**

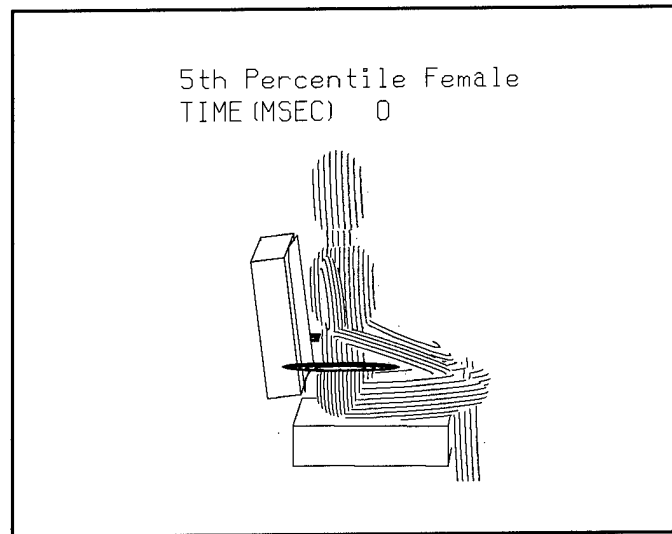
The ATB program can generate copious quantities of data concerning the predicted motions of body segments during a simulation, but it can be difficult to visualize and evaluate the gross body motion from this data. The VIEW program is used to convert this data into a series of two-dimensional line drawings of body segments and contact planes and provides a valuable aid to the simulation and modeling process. VIEW, also written in FORTRAN, must be run from DOS – it cannot be run from a DOS window in a Window's environment.

#### **1. Program Overview**

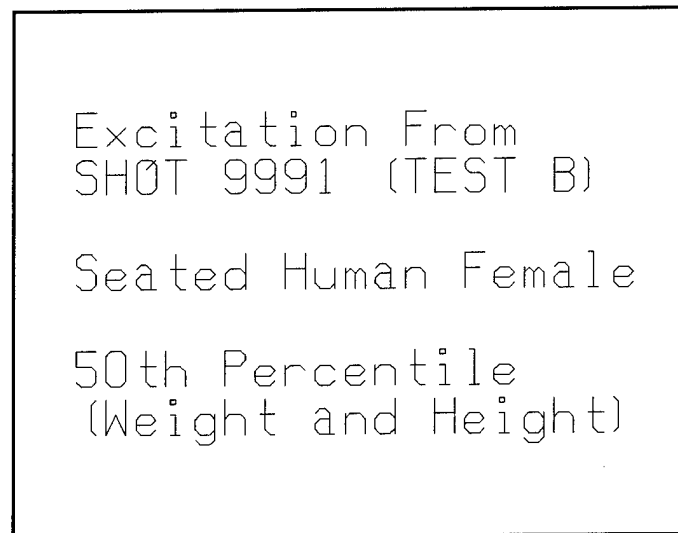
The VIEW program is capable of representing two basic types of elements – ellipsoids and polygons. The body segments are illustrated using line drawings of ellipsoids and the contact planes are illustrated using line drawings of polygons. There is no provision for plotting hyperellipsoids or simple belts, although harness belts can be rendered. Graphical output from the VIEW program may be directed either to a display terminal or to a variety of printers and plotters. An option exists to allow the graphical output be directed to a file for deferred plotting.

Figure 25 shows a sample graphics frame produce by the VIEW program. Note that there is, in addition to the time stamp, a title line displayed. This title line is optional, may be up to 40 characters in length, and, if specified, is displayed on every frame produced. In addition to the planes specified as contact surfaces in the ATB program model, the user may define a number of supplemental polygons to be plotted in each frame. There is no interaction between body segments and these supplemental polygons for VIEW is simply a graphics rendering utility, not a dynamic motion simulator as is ATB. The user may also identify certain ellipsoids and/or planes from the ATB model that are not to be rendered in the graphical output of the VIEW program. The user has control over the color in which each ellipsoid and plane is rendered, as well as the colors to be used in the title frame, title line and time stamp on each frame. The viewpoint or perspective from which the model is rendered must be specified by the user.

The user may also specify one or more title frames to appear at the beginning of the sequence of plotting frames. These title frames each contain 20 lines (not all must have text, some may be blank) of 30 characters per line. Figure 26 shows a sample title frame.



**Figure 25. Sample VIEW Drawing.**



**Figure 26. Sample VIEW Title Frame.**

## **2. File Structure**

The VIEW program uses two input files and produces one or two output files depending upon the desired device for graphical output.

### **a. Input files**

The two input files required by the VIEW program are a control (\*.VIN) file and a source data (\*.TP1) file. The \*.VIN file is a structured input file containing 80 character lines of formatted alphanumeric data much like the ATB input file. It is in the \*.VIN file that the user defines title frames and title strips, defines supplemental polygons if desired, specifies the colors for ellipsoids, planes and titles, determines the start, stop, and increment times, and sets up the viewpoint. See Ref. [3] for detailed information concerning the content and formatting for the \*.VIN file.

The \*.TP1 file is the output file produced by the ATB program that provides the data concerning the model construction and motion. Since the VIEW program is only a graphics rendering utility, it cannot interpolate between data points, thus each time step to be rendered as specified in the \*.VIN file, there must exist data at the same time step in the \*.TP1 file.

#### **b. Output files and devices**

One output file, the \*.VOU file, is always produced by the VIEW program. This file contains a formatted listing of the input data provided in the \*.VIN file, as well as debug information. The user has some control over what debug information is printed to the \*.VOU file – see Ref. [3] for details.

The second output file may or may not be produced, depending upon the user's choices for output device and format. These choices are made by specifying two parameters – MODEL and IOPORT. MODEL specifies the type of monitor or printer to be used and IOPORT specifies the hardware interface (parallel port, serial port, or data file). If the user elects to send the graphical output to a file (for deferred plotting), this file has the extension \*.VPL. Ref. [3] provides an extensive listing of the recommended combinations of MODEL and IOPORT for several printers, plotters, and displays.

### **D. IMAGE PROGRAM**

The IMAGE program, much like the VIEW program, is a tool used to visualize the gross body dynamics as computed using the ATB program. However, the IMAGE program generates solid object rendering in a 3-D environment and is a much more powerful tool. Unlike the ATB, GEBOD, and VIEW programs, IMAGE is written in C and must be run on a Silicon Graphics (SGI) computer. There is no published user's manual for the IMAGE program, but rather it comes with the program files in the form of a text file. For the convenience of the reader, the user's manual is included as APPENDIX A.

#### **1. Program Overview**

The IMAGE program, like the VIEW program, is capable of rendering only ellipsoids and polygons. However, instead of line and contour drawings, the IMAGE program produces shaded solid objects and allows the user to change the viewing angle and zoom in/out while the program is running.

Like VIEW, IMAGE produces only a series of still images based upon information generated by the ATB program. However, IMAGE provides the user with a VCR-like interface to control the display of the still images. By clicking on the appropriate buttons, the user can play the images like a movie, in forward or reverse, pause, restart the movie, step forward or backward frame by frame, or change the speed at which the images are displayed. By using the three mouse buttons the user can also zoom in or out (left button), rotate the image (middle button), or translate the image on the screen (right button). These changes in orientation can be made while the image sequence is playing, or while it is stopped. Figure 27 shows a sample frame from the IMAGE program.

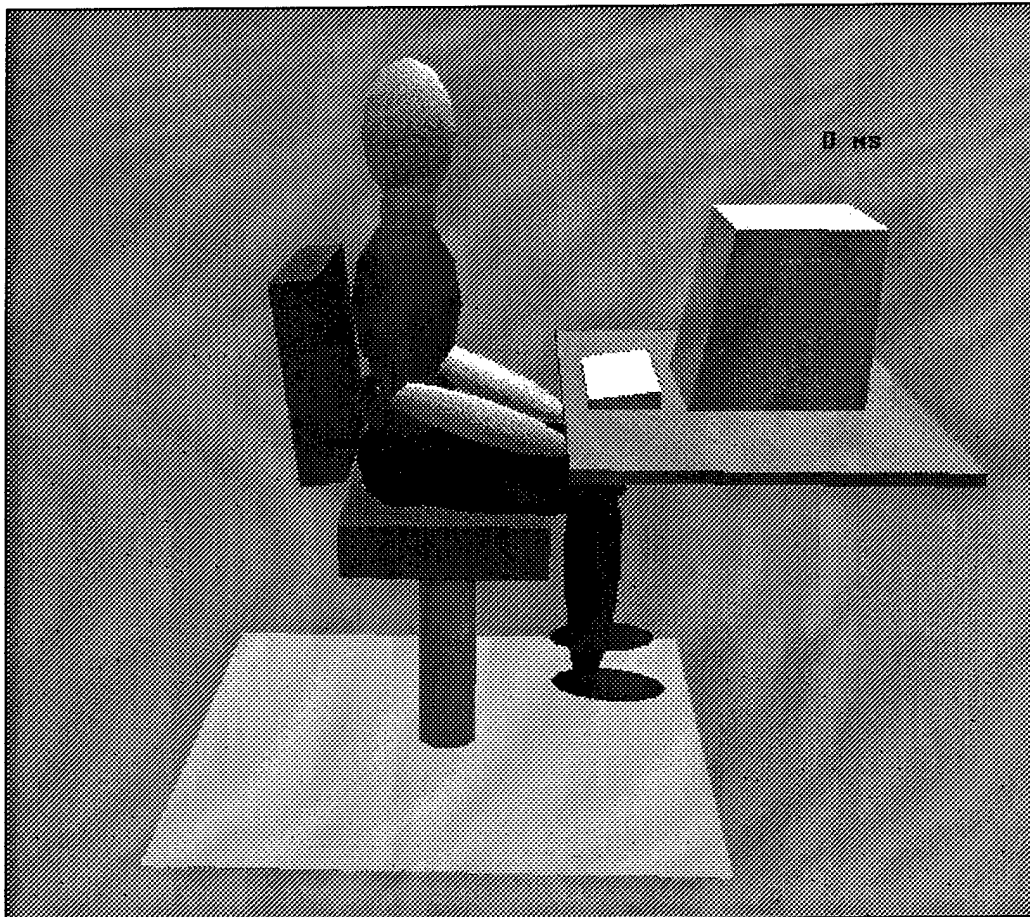
In addition to interactive controls, the user may add and delete planes, specify plane and ellipsoid colors, specify the direction from which incident light comes, and

specify a default viewing position through the use of a setup file described in the following section. Using the IMAGE program and a media-recording program, it is quite simple to create movie files and videotapes of the simulation.

## **2. File Structure**

The IMAGE program requires two input files. The first file is the \*.TP1 file containing the data generated by the ATB program. Just as in the VIEW program, the IMAGE program can only display images at times that information is stored in the \*.TP1 file. Unlike the VIEW program, where the user can specify a start, stop, and increment time, the IMAGE program displays all of the times for which there is data in the \*.TP1 file.

The second input file is a \*.setup file. It is in this file that the user defines the colors for the planes, ellipsoids, background and time stamp, designates any planes or ellipsoids to be removed, adds any desired planes, specifies the camera position and viewpoint, and specifies the light direction. The \*.setup file does not require the rigid structuring that the \*.AIN and \*.VIN files must maintain, but there are specific variable names that define the appropriate properties and a specific order in which the information must be included in the file. For more details concerning the \*.setup file and use of the IMAGE program, see APPENDIX A.



**Figure 27. Sample IMAGE Frame.**

### III. CREATING AN INPUT DECK

This chapter examines the process by which an input deck is created. One example is chosen and used throughout the remainder of the report for consistency. The chosen example involves the generation of a model of a Hybrid III Dummy seated in a standard operator's chair in a test vessel that is subjected to an underwater explosion. Measured accelerations of the deck to which the chair is attached, and of the head, chest, and pelvis of the dummy, along with video footage of the test, provide a basis for validation of the simulation. Following validation, the model is extended to simulate humans and to estimate injury potentials. From the videotape of the test, a still frame image, Figure 28, has been captured to aid in the construction of the environment and initial positioning of the test subject.

Each section covers a major category of the input deck data. In each section, the process by which the required data is obtained is discussed, and then the manner in which the data is formatted as required by the ATB program is illustrated. Note that this report does not replace Ref. [1], but rather illustrates the application to a single example problem. All formatting requirements are fully detailed in Ref. [1].

Finally, the completed input deck (\*.AIN file), with a major portion of the tabulated excitation history removed for brevity, is included as APPENDIX B. In addition, the main output file (\*.AOU) for this input deck, again with a major portion of the tabulated excitation history removed for brevity, is included as APPENDIX C to aid in the interpretation of the ATB formatted input data.

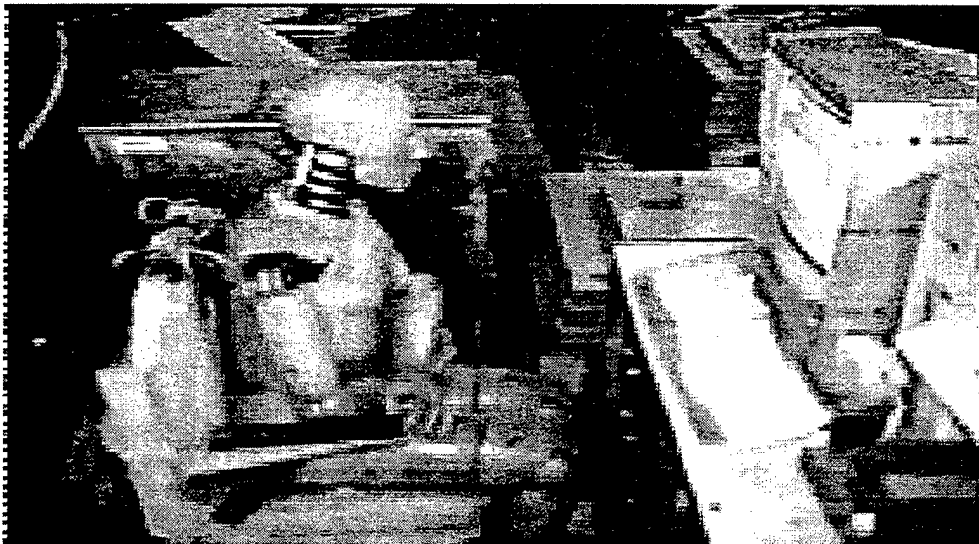


Figure 28. Example Test Setup.

When first using the ATB program, it is advisable to start with an example input (\*.AIN) file, and the associated main output (\*.AOU) file, and compare the two. The \*.AOU file contains the information from the \*.AIN file, but in an easy to read tabular form. Then, make small modifications to the existing \*.AIN file, run ATB, and examine

the results. This is much easier than trying to create an \*.AIN file from scratch due to the extensive formatting requirements

## A. USING GEBOD TO GENERATE BODY SET DATA

Perhaps the easiest step in creating the input deck is to generate the required data for the test subject, be it an ATD or a human. The GEBOD program, using simple input from the user, generates the appropriate information in the correct format for use in the \*.AIN input file to the ATB program. In this case, the test subject is a 50<sup>th</sup> percentile male Hybrid III dummy, one of the ATD's for which GEBOD can generate the body data.

### 1. Running the GEBOD Program

In order to generate the body data, the GEBOD program is executed by typing "GEBODIV1" at a DOS prompt (GEBOD may be executed from a DOS window). Figure 29 shows the display from the run of GEBOD used to generate the body data set for the 50<sup>th</sup> percentile male Hybrid III dummy, using English units and creating an ATB formatted input file. The dark text is generated by the GEBOD program; the lighter text is user input from the keyboard.

The first required input is a description of the test subject. This description is printed in the each of output files and should sufficiently describe what the associated data represents. In this case, the description "Seated, 50<sup>th</sup> %-ile male Hybrid III" was used as can be seen from the first line of lighter text in Figure 29. GEBOD then redisplay the description and makes the next request for information – output file name. Again, it helps to make the output file name somewhat descriptive. A word of caution, though – if there is an existing \*.AIN file with the same filename, it will be overwritten if that filename is used for output of ATB formatted data in GEBOD. In this case, the filename "SM50H3" was chosen and represents Seated Male 50<sup>th</sup> percentile Hybrid 3.

Next, the user is prompted to choose what kind of test subject is to be modeled, as shown in Figure 29. Since the subject used in the actual test was a 50<sup>th</sup> percentile male Hybrid III dummy, option 5 is chosen. Had the subject been a human (options 1-4), further information would have been required by the GEBOD program. This will be covered in detail in the section concerning extending the validated model to the simulation of human motion.

English or metric units must be specified. The selection is entirely up to the user, although the entire ATB input file must be in consistent units. The ATB user's manual [Ref. 1], as well as this example, utilize the units of inches, pounds, and seconds. In addition, Ref. [1] cautions that if other units are used, it may be necessary to modify the field widths of some of the output format statements.

Since in this case the purpose of running the GEBOD program was to generate body data for use in an ATB input file, ATB model formatted output is desired. In addition, since there is only one subject in this example, no further body description data sets are required.

```

PROGRAM GEBOD
GEBOD GENERATES BODY DESCRIPTION DATA
SUITABLE FOR INPUT TO THE ATB MODEL
PLEASE ENTER A DESCRIPTION OF THE SUBJECT (<60 CHARS.)

```

```

Seated, 50th %-ile male Hybrid III

```

```

ENTER FILENAME FOR ALL OUTPUT FILES,
EXTENSIONS WILL BE ASSIGNED:

```

- 1) CHILD (2 - 19 YEARS)
- 2) ADULT HUMAN FEMALE
- 3) ADULT HUMAN MALE
- 4) USER-SUPPLIED BODY DIMENSIONS
- 5) SITTING HYBRID III DUMMY (50%)
- 6) STANDING HYBRID III DUMMY (50%)
- 7) HYBRID II DUMMY (50%)

```

ENTER NUMBER CORRESPONDING TO DESIRED SUBJECT TYPE

```

```

-

```

```

SELECT UNITS FOR OUTPUT

```

- 1) ENGLISH
- 2) METRIC

```

IS ATB MODEL FORMATTED OUTPUT DESIRED (Y/N) ?

```

```

-

```

```

IS IT DESIRED TO PRODUCE ANOTHER BODY DESCRIPTION DATA SET (Y/N) ?

```

```

-

```

**Figure 29. GEBOD Execution Example.**

## 2. GEBOD Program Output Files

Running the GEBOD program as described in the above paragraphs results in the generation of two output files – a \*.TAB and a \*.AIN file. In this example, the files SM50H3.TAB and SM50H3.AIN have been created in the same directory in which the GEBOD program resides.

The \*.TAB file generated from the above run of the GEBOD program is included as APPENDIX D. This information is the same as is contained within the ATB formatted (\*.AIN) file, but in the \*.TAB file, it is in tabular form and is much easier to read. In order to make sense of the \*.AIN file, which is included as APPENDIX E, it helps to compare the information it contains with the corresponding portion of the \*.TAB file. Note that in the \*.AIN file, each line has an associated card number (Card B.1, Card B.2, etc.) located at the right margin. The \*.TAB file groups the like cards together under headings, also located at the right margin. For example, the B.2 cards contain the mass and geometrical properties of the segments making up the body of the Hybrid III dummy. The information as presented in the \*.TAB file is much easier to read, whereas reading the \*.AIN file requires the user to consult the appropriate section in Ref. [1].

Notice that the \*.AIN file contains information on Cards B.1 through B.6, D.1, E.1 through E.4, E.7, and F.4 through F.5. When the complete input file is constructed, this information can easily be cut and pasted in the appropriate locations with no change in formatting required.

Figure 30 shows the segment and joint numbering scheme created by GEBOD for the 50<sup>th</sup> percentile male Hybrid III dummy. The segments and joints are numbered on the figure as they are shown in the B.2 and B.3 cards. The fourth column on the B.3 cards lists the JNT parameter, which defines how the segments are connected. As shown in Figure 30, the Pelvis (Joint J=1) connects the Middle Torso (Segment J+1=2) to the Lower Torso (Segment JNT=1).

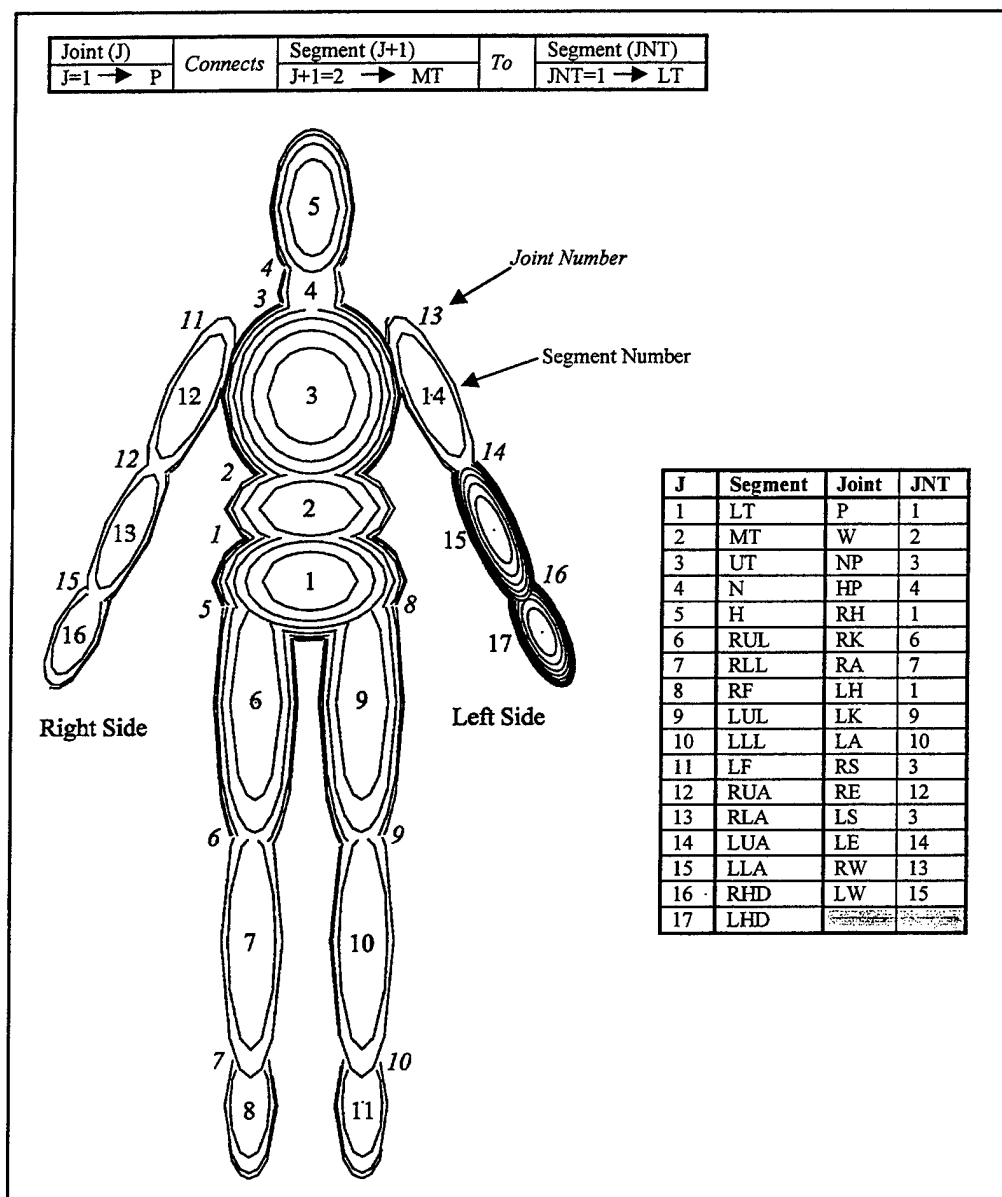


Figure 30. Standard 17 Segment Body. After Ref. [4]



## **B. BUILDING THE ENVIRONMENT**

Constructing the model of the environment within which the test subject exists is quite possibly the most time consuming portion of creating the input deck. The more information that is available concerning the environment to be modeled, the easier the process will be. Overall, steps for constructing a model of the environment include:

1. Choosing a coordinate system
2. Determining what contact surfaces are to be modeled
3. Drawing a detailed diagram of the contact surfaces in the appropriate coordinate system
4. Creating any additional features such as harness belts, spring-dampers, or airbags.

### **1. Choosing a Coordinate System**

There are several aspects to choosing coordinate systems. The coordinate system should be easy to work with in terms of defining the components of the model. It would be convenient to have the coordinate system be consistent with input excitation data or data to be used for validation, thus preventing or reducing the need to convert or transform either the measured data or the output from the ATB program. In addition, there are sign conventions related to the use of ATD's that should be considered when first setting up the model. A little time and forethought can greatly reduce the effort required in later steps.

#### **a. Various coordinate systems in the ATB program**

There are several coordinate systems utilized by the ATB program and they may be grouped in the following categories:

1. Inertial
2. Vehicle
3. Local body segment
4. Principal
5. Joint
6. Contact ellipsoid

The inertial coordinate system is assumed by the ATB program to have its origin at the point (0,0,0) and the user may equate this point to any convenient location within the model. It is within this frame of reference that the locations and orientations of the vehicle and local body segment coordinate systems are defined. The inertial coordinate system is partially specified by defining the gravity vector. Typically, this vector will be specified as (0,0,g) such that the positive Z-axis points down. Further convention would have the X-axis pointing forward and, by the right hand rule, the Y-axis pointing to the right as shown in Figure 31.

The vehicle coordinate system is typically the coordinate system in which most contact surfaces will be defined. It is defined by specifying the (x,y,z) coordinates of the origin with respect to the inertial coordinate system, then by specifying the yaw, pitch and roll angles to define the coordinate transformation matrix. The standard axis transformation, as shown in Figure 32, is to yaw about the Z axis, pitch about the new Y

(now  $Y'$ ) axis, the finally roll about the new  $X$  (now  $X''$ ) axis to yield the  $(X^*, Y^*, Z^*)$  system.

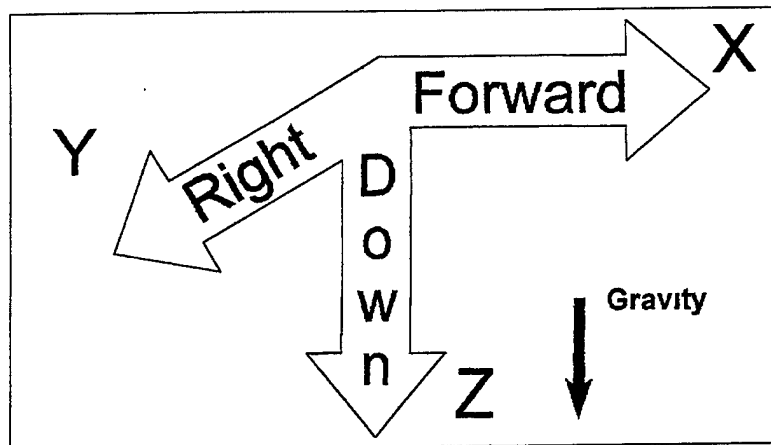


Figure 31. General Coordinate System Sign Convention. After Ref. [4]

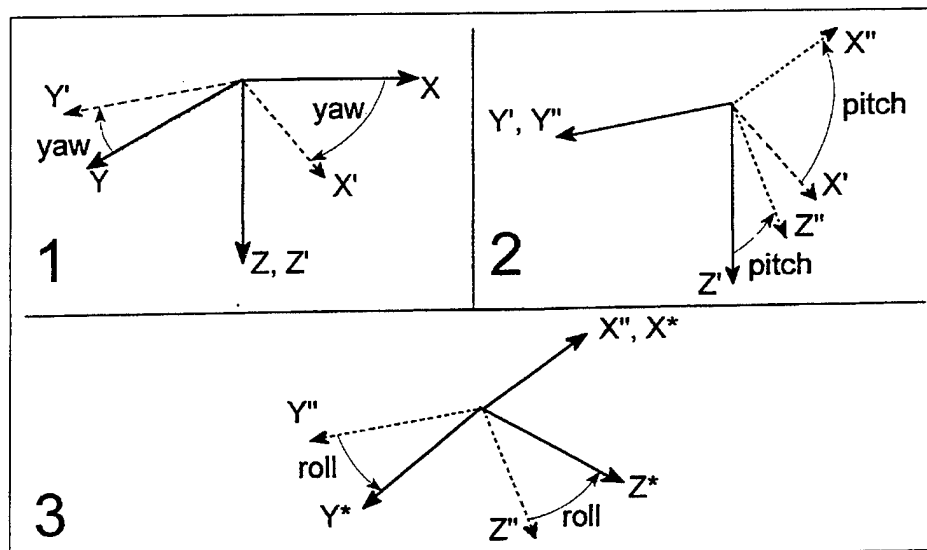


Figure 32. Standard Yaw, Pitch, Roll Sequence. After Ref. [4]

Body segments are defined by the locations of their centers of mass and the centers of their associated contact ellipsoids. Joints locations are defined by the coordinates of their centers. Figure 33 shows this arrangement in terms of the inertial coordinate system. The local body segment coordinate system has its origin located at the center of mass of the segment. When generated by GEBOD, the standard convention is that the body is standing upright, with arms hanging at the sides and feet dangling. In this position, all of the local body segment coordinate systems are aligned such that  $+Z$  is down (from head to feet),  $+X$  is forward (from back to front), and  $+Y$  is to the right (from left to right). All input or output concerning the segments is referenced to the local body segment coordinate systems.

There is another coordinate system associated with each body segment, the principal coordinate system. This coordinate system has its origin coincident with the local body segment coordinate system at the center of mass of the segment. However, if the axes of the principal moments of inertia of the segment are not aligned with the local body segment coordinate system, then the yaw, pitch and roll angles that define the transformation must be specified. The orientation of the principal axes with respect to the local body segment axes is fixed. This coordinate system is illustrated in Figure 34. It is in the principal coordinate system that the ATB program performs the calculations for the dynamics of the motion of the body segment. The program transforms input data from the local body segment coordinate system into the principal coordinate system prior to performing calculations. Then, once the calculations have been performed, the data is transformed back into the local body segment coordinate system prior to output.

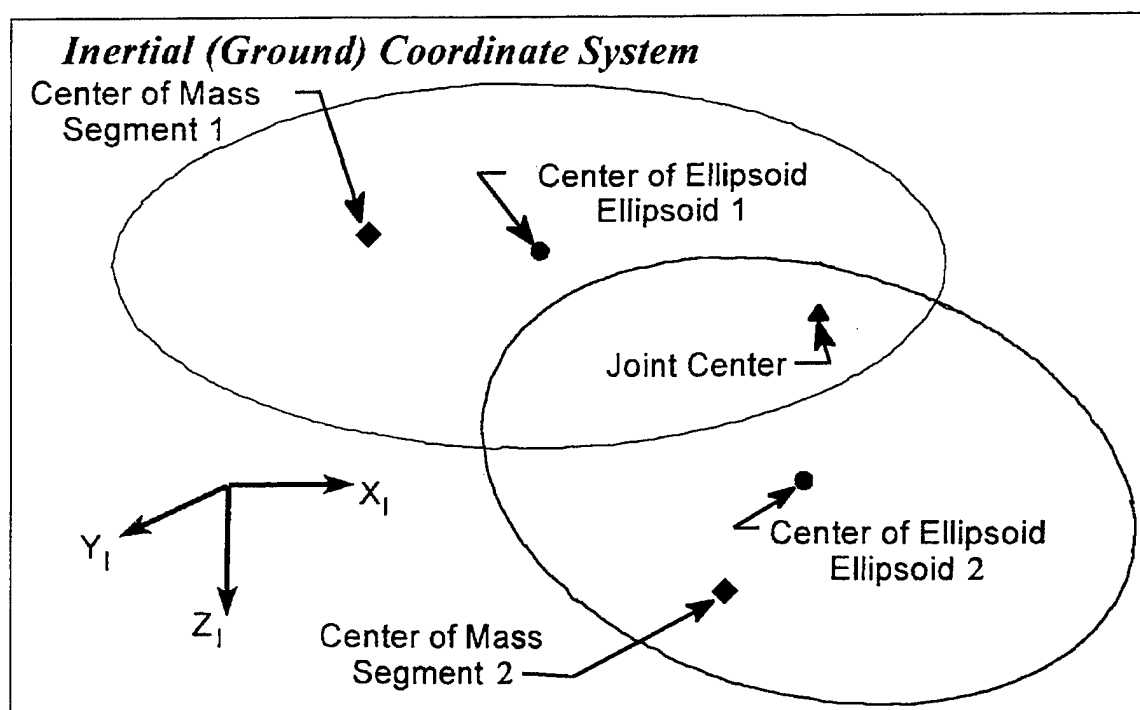


Figure 33. Inertial Coordinate System. After Ref. [4]

Associated with each joint are two coordinate systems. The location of the center of the joint is specified with respect to the local body segment coordinate system for each of the segments forming the joint. This location, and the associated orientation of the joint axis as defined by their yaw, pitch and roll angles, are fixed for each segment. Figure 35 shows a joint ( $J=1$ ) with its two associated coordinate systems, one attached to segment  $J+1$  ( $=2$ ) and the other attached to segment  $JNT$  ( $=1$ ). The joint forces and torques are computed based upon the relative orientation of the two joint coordinate systems.

Finally, for each contact (hyper) ellipsoid there is a coordinate system. The axes of this coordinate system are aligned with the  $x$ ,  $y$ , and  $z$  semi-axes used to define the dimensions of the (hyper) ellipsoid. The location of the center of the

coordinate system, and the orientation, are defined by the (x,y,z) coordinates and yaw, pitch, and roll angles with respect to the local segment coordinate system with which the (hyper) ellipsoid is associated.

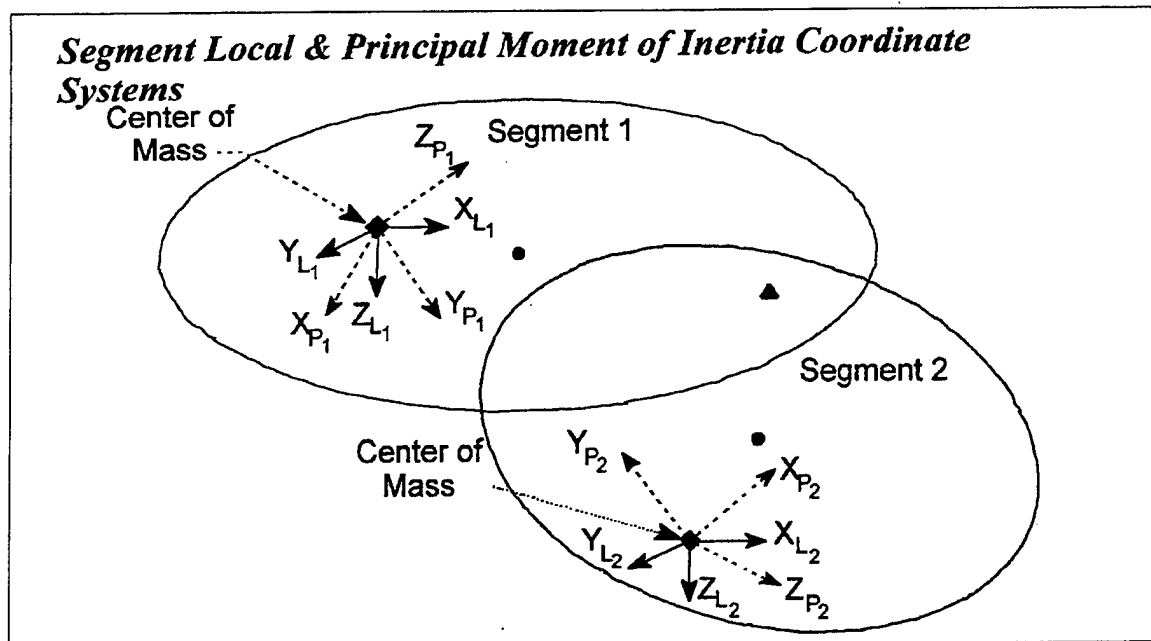


Figure 34. Local Body Segment Coordinate System. After Ref. [4]

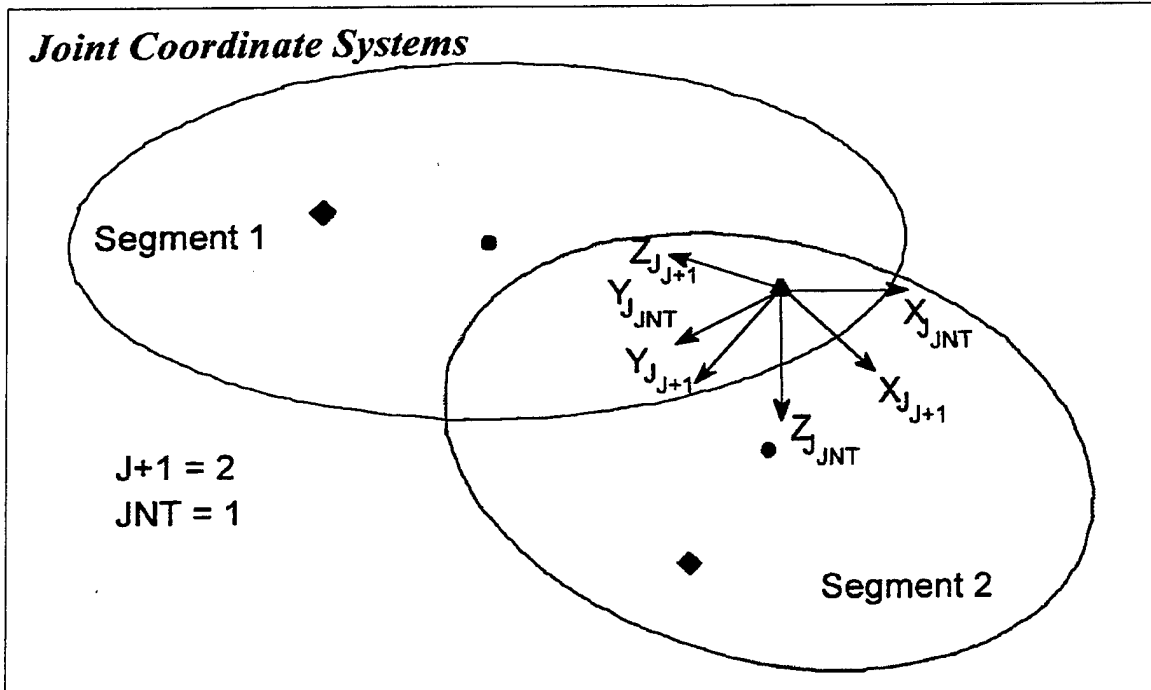


Figure 35. Joint Coordinate Systems. After Ref. [4]

### b. Sign convention for crash testing

There is a standard sign convention, as specified in the Society of Automotive Engineers (SAE) Information Report J1733, associated with the used of ATD's [Ref. 6]. This convention, which applies to forces, moments, accelerations and displacements, is consistent with the definition of the body segment coordinate system described above. The convention, for both standing and seated postures, is illustrated in Figure 36.

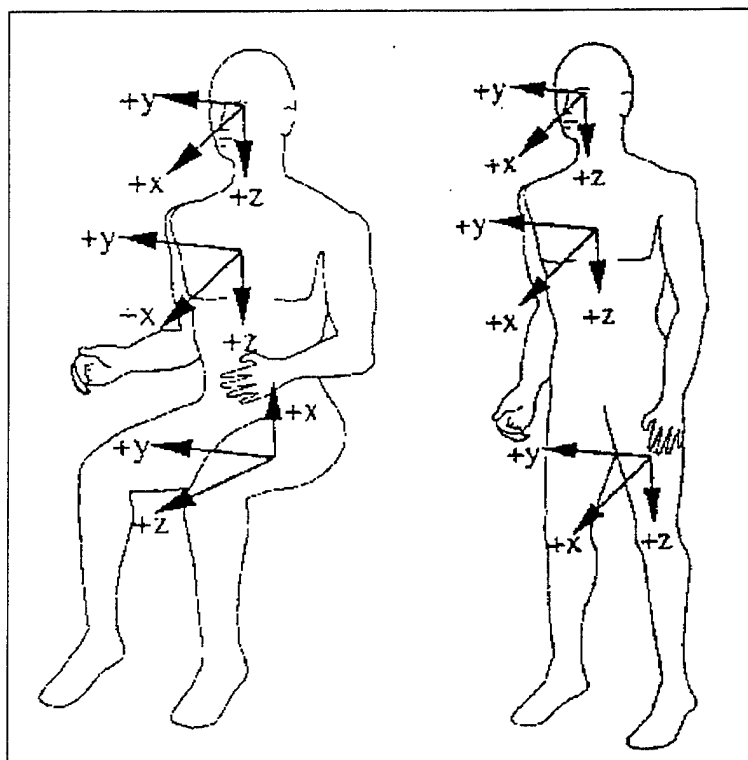


Figure 36. SAE Sign Convention. After Ref. [6]

### c. Compatibility with input and/or output data

If modeling and test instrumentation sign conventions can be coordinated prior to conducting the test, assigning and keeping track of coordinate systems is greatly simplified. However, if no thought is given to modeling prior to conducting a test, as was the case in this example, more effort will be required for pre- and post-processing of data. It is relatively simple to make whatever transformations may be required to input and/or output data using either a spreadsheet or perhaps a simple conversion program written in MATLAB or FORTRAN.

In this example, the ATD was seated, facing starboard, in a standard operator's chair on the upper platform of a two-platform test vessel that was subjected to an underwater explosion. See Figure 37 for the arrangement of this platform. The locations of the accelerometers are labeled using a code beginning with the letter A (for accelerometer), followed by four numbers (identification numbers), and then followed by an A, an F, or a V. The A, F, and V refer to the orientation: A=athwartships, F=fore-and-

aft, and V=vertical. Some codes have an I at the end to signify that the orientation of the accelerometer is inverted. The convention used in placing and aligning these accelerometers was that forward was positive for F-oriented accelerometers, up was positive for V-oriented accelerometers, and port was positive for A-oriented accelerometers.

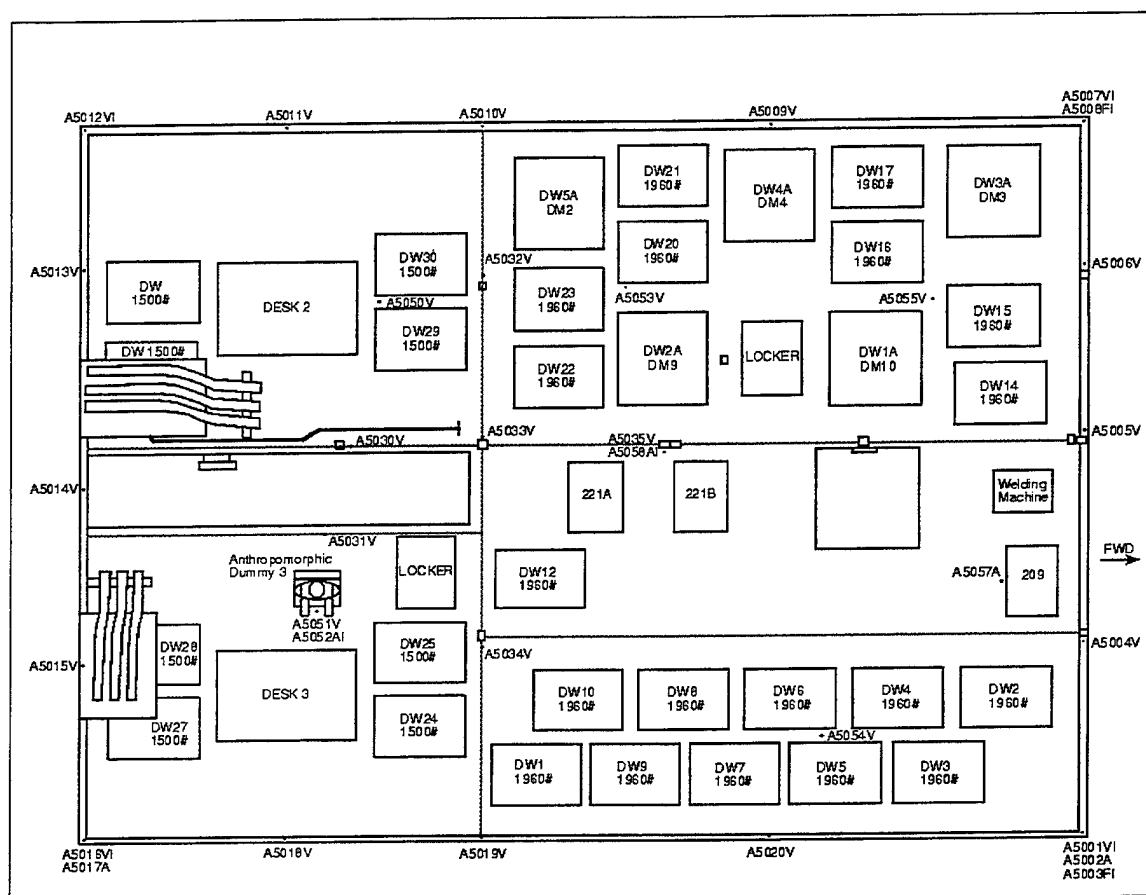


Figure 37. Accelerometer Locations (First Platform). From Ref. [10]

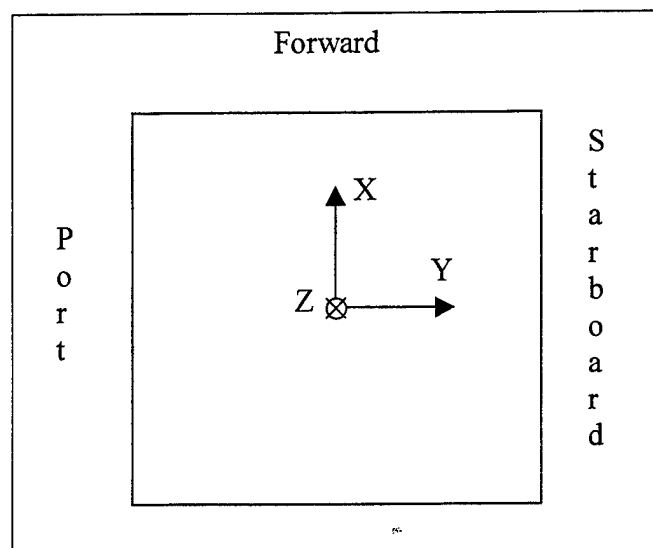
For the example, the choice was made to align the inertial coordinate system such that the X-axis pointed in the forward direction. In addition, it was desired to have the positive Z-axis pointing down; thus, the Y-axis was defined (via the right hand rule) to point to starboard. This orientation is shown in Figure 38. Since the ATD is seated facing starboard, it would have been a better choice to align the X-axis of the inertial coordinate system such that it pointed starboard to be consistent with the sign convention for ATD's. The location of the origin of the inertial coordinate system was selected to be on the deck at the center of the base of the chair in which the ATD was seated. This choice was made so that the origin coincided roughly with the location of the accelerometers at the base of the chair.

In order to relate the data as recorded to the inertial coordinate system, and to avoid confusion later, it is convenient to create a simple table. The conversion from the test vehicle (SSTV) to the model (ATB) is shown in Table 4. For example, to transfer

the data from an athwartships mounted accelerometer into the inertial coordinates, all that is required is multiplying the data by negative one.

**Table 4. Test Vessel to Model Conversion**

SSTV Coordinates	Multiplier	Inertial Coordinates
F (fore and aft)	+1	X
FI (fore and aft – inverted)	-1	X
A (athwartships)	-1	Y
AI (athwartships – inverted)	+1	Y
V (vertical)	-1	Z
VI (vertical – inverted)	+1	Z



**Figure 38. Inertial Coordinate System Definition.**

## 2. Selecting Contact Surfaces

Once the basics of selecting and locating an inertial coordinate system have been completed, the next logical step is to decide how much of the environment must be modeled. The only items that need be modeled are those with which the test subject interacts. Other items may be modeled, if desired, to provide additional visual reference when using the VIEW program. It is important to keep in mind the limitations on the number of contact planes, contact (hyper) ellipsoids, plane-segment contacts, and segment-segment contacts allowed by the unmodified ATB program.

In this example, in addition to the deck, the only object to be modeled was the chair in which the ATD was seated. There was no apparent contact with the desk, so this object was not included in the modeling for validation. The important components of the chair included the seat bottom (cushion and right, left, and front sides), seat back (cushion and right, left, and top sides), left and right armrests, and lap belt. The pedestal supporting the chair and the footrest were not thought to interact with the ATD and thus were not considered.

Once the objects to be modeled are identified, the next step is to determine how to model them. Contact surfaces can be modeled as either planes or (hyper) ellipsoids and belts can be modeled as either simple or harness belts. In this example, it was decided to model the surfaces of the seat (bottom cushion, right, left, and front sides; back cushion, right, left, and top sides), as well as the deck, as planes. An alternative would have been to model the seat bottom as one hyperellipsoid and the seat back as a second hyperellipsoid. A drawback to this method is that there are only 40 segment-segment contacts allowed. This number includes the expected interactions between the individual body segments (e.g., right lower arm and right upper leg) and it is quite easy to reach the limit if (hyper) ellipsoids are used as contact surfaces. The decision was made to model the armrests as ellipsoids, although the use of hyperellipsoids might have been a better choice in order to capture their physical dimensions more accurately. A simple, vice harness, belt was deemed adequate for the model. Table 5 summarizes the surfaces to be modeled and the corresponding model element selected.

**Table 5. Correlation of Model Element to Physical Surface**

Physical Surface	Selected Model Element
Seat Bottom Cushion	Plane
Seat Bottom Right Side	Plane
Seat Bottom Left Side	Plane
Seat Bottom Front Side	Plane
Seat Back Cushion	Plane
Seat Back Right Side	Plane
Seat Back Left Side	Plane
Seat Back Top	Plane
Right Arm Rest	Ellipsoid
Left Arm Rest	Ellipsoid
Lap Belt	Simple Belt
Deck	Plane

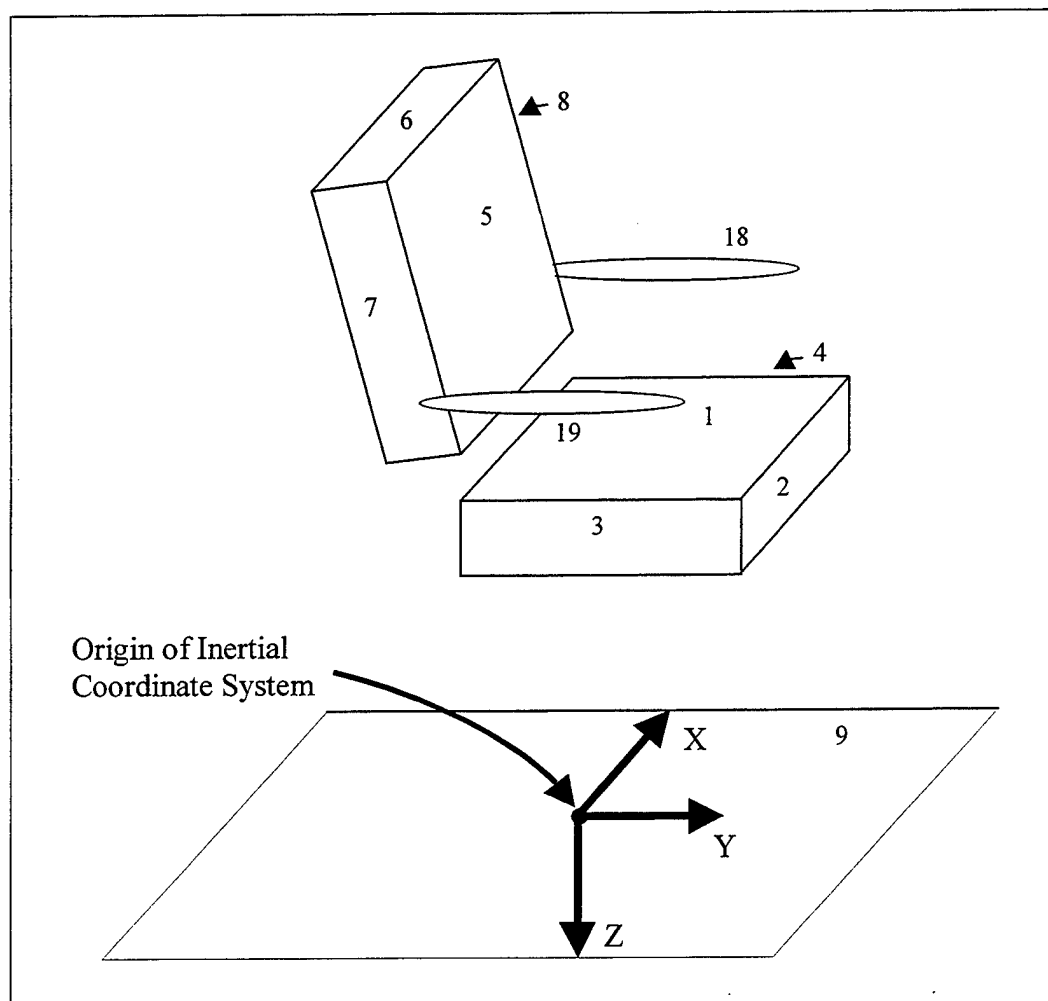
### 3. Drawing a Picture and Defining Contact Surfaces

After selecting the physical objects to be modeled, and determining the types of ATB elements to use for the modeling, the next step is to define the physical properties of the ATB elements. It is highly recommended that a few sketches be drawn and labeled to avoid confusion. One method would be to create a drawing similar to the one shown in Figure 39. This gives an overall view of the objects to be modeled, includes the origin and orientation of the inertial coordinate system (also selected as the coordinate system for the vehicle), and numbers all of the contact surfaces to be modeled. Note that the ellipsoids representing the arm rests are numbered 18 and 19. This is because the test subject is created from segments 1 through 17.

For each plane to be modeled, three corner points (P1, P2, and P3) must be specified to define not only the location and size, but also the orientation of the parallelogram representing the surface. Refer back to Figure 4 for an illustration of how a plane is defined in the ATB program. It is very important to ensure that the normal to



the plane, as defined by the vector formed by crossing  $P_1P_2$  into  $P_1P_3$ , is correctly oriented. Thus, sketching the points  $P_1$ ,  $P_2$ , and  $P_3$ , and the outward normal, is a good idea. Figure 40 illustrates this process for the right side of the seat bottom, plane number three.



**Figure 39. Sketch of Operator's Chair.**

Once the three points defining each plane have been identified, and the correct orientation of the outward normals verified, the next step is to determine the coordinates of each of these points. Dimensions for the operator's chair in this example were determined by physical measurement and the resulting coordinates of the points defining each of the identified planes are shown in Table 6.

The planes defining the chair and deck are rigidly attached to the vehicle and there can be no relative motion between them. This does not exactly model reality in that there is some flexibility in the real chair. In addition, the seat back, which is adjustable for angle, is definitely not rigidly attached to the seat bottom. However, the motion between the seat back and the seat, and between the seat and the deck, is assumed to be relatively minor. If a more sophisticated model was required, then the seat back and seat

bottom planes could each be attached to separate segments. These segments could then be connected to each other and to the deck using appropriate joint types and parameters.

From examination of the videotape of the actual test, significant motion of the armrests was observed. Thus, it was desired to have these armrests free to pivot about their hinges with appropriate joint and inertial parameters. The physical dimensions of the armrests were first defined. Since segments were used to model the armrests, it was necessary to specify the center of mass and inertial properties of the segment and the center, semi-axis lengths, and orientation of the associated contact ellipsoids. In addition, the location and orientation of the joint used to connect the armrest segments to the vehicle must also be specified.

**Table 6. Coordinates of Points Defining a Contact Plane.**

Plane #	Plane ID	Point	X	Y	Z
1	Seat Cushion. Bottom.	P1	-9.50	-9.25	-24.50
		P2	-9.50	9.25	-24.50
		P3	9.50	-9.25	-24.50
2	Seat Cushion. Front.	P1	9.50	9.25	-19.75
		P2	9.50	9.25	-24.50
		P3	-9.50	9.25	-19.75
3	Seat Cushion. Right Side.	P1	-9.50	9.25	-19.75
		P2	-9.50	9.25	-24.50
		P3	-9.50	-9.25	-19.75
4	Seat Cushion. Left Side.	P1	9.50	-9.25	-19.75
		P2	9.50	-9.25	-24.50
		P3	9.50	9.25	-19.75
5	Seat Back.	P1	-9.50	-8.30	-28.25
		P2	9.50	-8.30	-28.25
		P3	-9.50	-10.25	-44.55
6	Seat Back. Top.	P1	-9.50	-10.25	-44.55
		P2	9.50	-10.25	-44.55
		P3	-9.50	-14.22	-44.07
7	Seat Back. Right Side.	P1	-9.50	-12.27	-27.77
		P2	-9.50	-8.30	-28.25
		P3	-9.50	-14.22	-44.07
8	Seat Back. Left Side.	P1	9.50	-12.27	-27.77
		P2	9.50	-14.22	-28.25
		P3	9.50	-8.30	-44.07
9	Deck.	P1	-25.00	-25.00	0.00
		P2	-25.00	25.00	0.00
		P3	25.00	-25.00	0.00

The armrests were measured to be 14 inches long, 2 inches wide, and 1 inch high. The weight of each armrest was estimated to be 2 pounds. While the actual armrests were rectangular, ellipsoids, with semi-axis lengths equal to half of the actual length, width, and height, were chosen as the modeling elements. As previously mentioned, using a hyperellipsoid as the modeling element would allow the actual physical shape of the armrest to be more closely approximated. The armrests were assumed to be

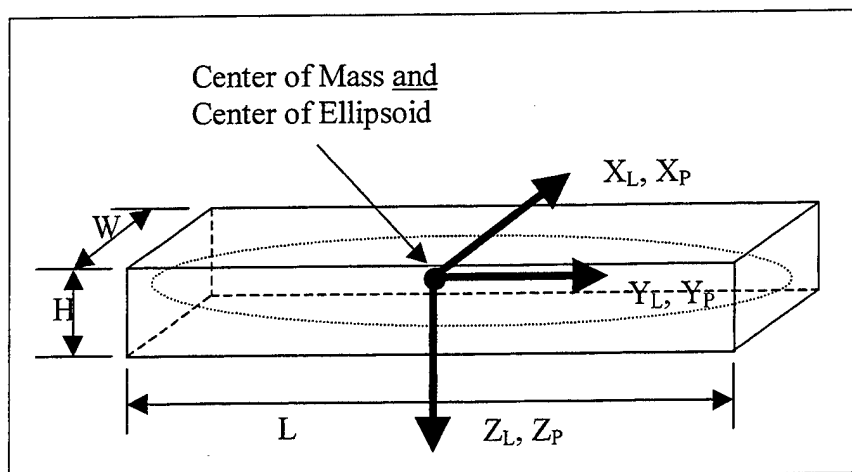
The principal moments of inertial for the armrests were computed using Equations 3, 4, and 5. The physical dimensions and resulting moments of inertia are summarized in Table 7.



$$I_z = \frac{1}{12} m (L^2 + W^2) \quad (5)$$

**Table 7. Armrest Physical Data.**

Armrest	Principle Moment of Inertia (lb sec <sup>2</sup> in)			Semi-axis Lengths (in)			Center of Ellipsoid Offset (in)		
	x	y	z	x	y	z	x	y	z
Left	0.0850	0.0022	0.0863	1.00	7.00	0.50	0.00	0.00	0.00
Right	0.0850	0.0022	0.0863	1.00	7.00	0.50	0.00	0.00	0.00



**Figure 41. Armrest Detail.**

In addition to specifying the physical dimensions and moments of inertia for the armrests, the parameters for the joints connecting the armrests to the vehicle must also be specified. The logical choice for the joint type (see Figure 1 for options) is a pin joint. The specification of a joint requires that not only the type of joint must be specified, but also that the location and orientation of the two sets of joint axes must be specified (see Figure 35 for joint coordinate system details). The location of the joint center (origin of the joint coordinate systems) is easily specified. The point was chosen to be one-half inch from the end and centered on the major axis of the ellipsoid and the coordinates are specified in both the vehicle and the armrest local coordinate systems (see Table 8 for values). Reference [1] requires that pin joints have the y-axis as their axis of rotation, thus requiring a coordinate transformation for both sets of joint axes. A yaw of 90 degrees is necessary to align the y-axes of both joint coordinate systems with the desired axis of rotation of the armrest (see Figure 42 for details).

The armrests on the actual chair were free to move from a horizontal position to a position roughly parallel to the seat back. This range of motion was estimated to be 97 degrees and, within this range, there was no resistance (other than friction). At the stops (horizontal and parallel with the seat back), however, there was considerable resistance to further motion. This behavior can be modeled using a joint stop angle of 48.5 degrees (half of 97 degrees), a linear spring coefficient of zero, and a large quadratic spring coefficient (refer to Figure 2, S1=0, S2=large number, S5=48.5 deg). As previously stated, the joint torques are computed based on the relative orientation of the two sets of joint axes. This angle (flexure, or rotation about the y-axis, for a pin joint) is referenced

to the JNT segment set of axes as the center of symmetry. In other words, if the JNT and J+1 segment joint axes are coincident, the segment is oriented such that there is no flexure about the joint ( $\theta=0$  in Figure 2). So, for the armrest to be at one joint stop angle ( $-48.5$  deg) when in the horizontal position and at the other joint stop angle ( $+48.5$  deg) when aligned with the seat back, the center of symmetry (JNT segment joint axes) must be rotated 48.5 degrees counter-clockwise from the J+1 segment joint axes. This condition is illustrated in Figure 42 and the corresponding angles listed in Table 8. Note that is would have been equivalent, and probably less confusing, to have the J+1 segment joint axes aligned with the segment and to have the JNT segment joint axes rotated 48.5 degrees counterclockwise. This would have the  $X_{JNT}$  aligned with the physical center of symmetry of the armrest range of motion.

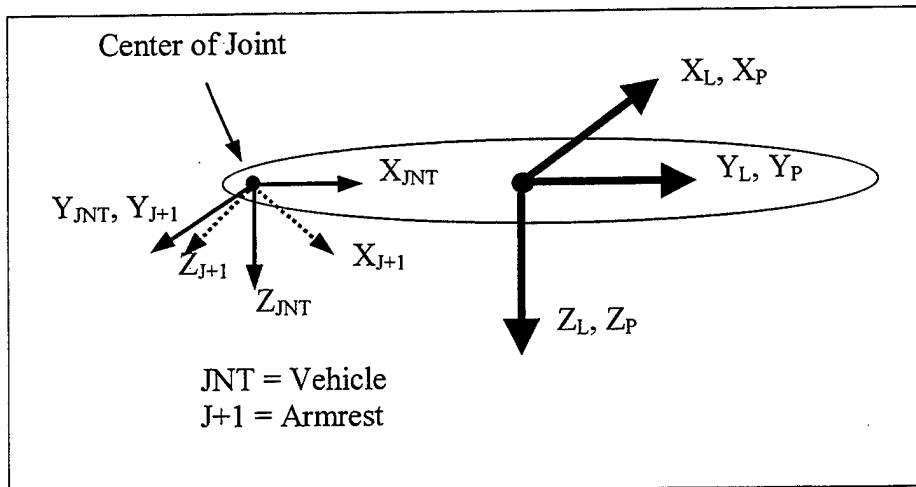


Figure 42. Armrest Joint Detail.

Table 8. Armrest Joint Parameters.

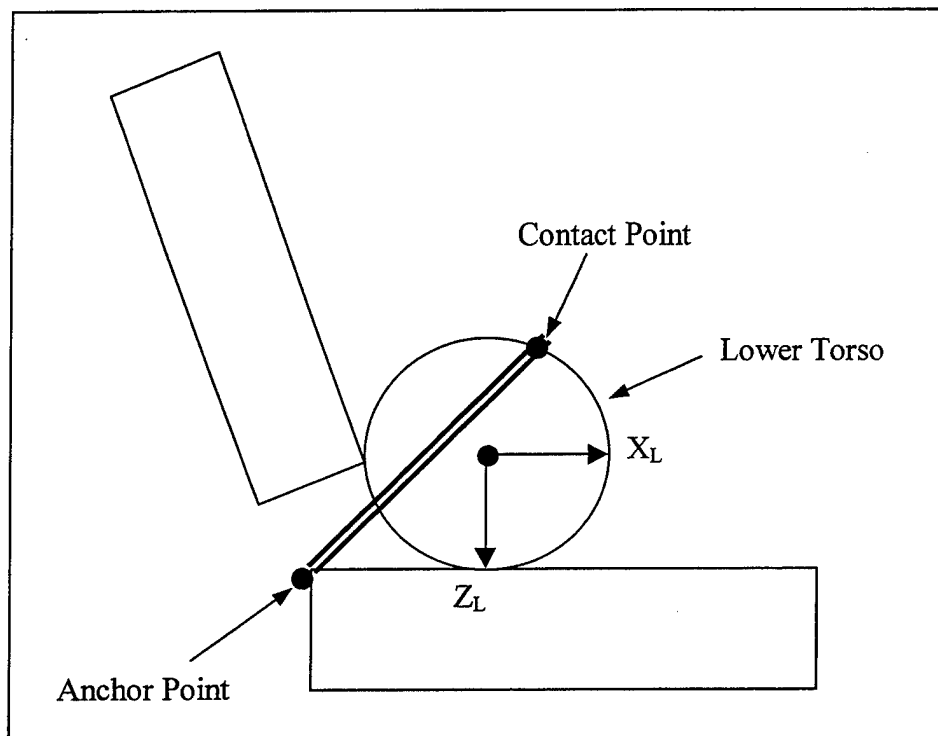
Armrest	Location (in)						Joint Axes Orientation (deg)					
	Vehicle Coordinates			Armrest Coordinates			WRT Vehicle Axes			WRT Segment Axes		
	x	y	z	x	y	z	yaw	pitch	roll	yaw	pitch	roll
Left	10.50	-10.00	-31.75	0.00	-6.50	0.00	90.00	0.00	0.00	90.00	-48.50	0.00
Right	-10.50	-10.00	-31.75	0.00	-6.50	0.00	90.00	0.00	0.00	90.00	-48.50	0.00

The only component of the model yet to be discussed is the lap belt. It was decided that use of a simple belt, vice a harness belt, would be adequate in this example problem. A simple belt, as previously described (see Figure 18), requires only that the two anchor points and a fixed contact point on a segment, plus an initial slack length, be specified. The anchor points in this example are simply the two points at which the lap belt is attached to the chair. The belt runs across the lap, so the lower torso is the segment that will be allowed to interact with the belt. The contact point on the lower torso was specified such that it was aligned with the center plane of the body and roughly 60 degrees above horizontal. Figure 43 shows the side view of the lap belt specification with the armrests and remainder of the body segments removed for clarity. The coordinates of these three points are specified in Table 9. The initial slack for the lap belt

was set to zero (recall that simple belts cannot be pre-tensioned by specifying a negative initial slack).

**Table 9. Lap Belt Anchor/Contact Point Locations.**

Point	Coordinate System	X (in)	Y (in)	Z (in)
Left Anchor	Vehicle Local	9.50	-9.50	-24.50
Right Anchor	Vehicle Local	-9.50	-9.50	-24.50
Segment Contact	Lower Torso Local	2.72	0.00	-4.03



**Figure 43. Lap Belt Detail.**

#### **4. Formatting the Data**

Now that the necessary data concerning the definitions of the contact surfaces and the lap belt has been accumulated, the next step is to format the data in accordance with Ref. [1]. Formatting the contact surface (including the armrest joint parameters) and lap belt data will be discussed in the following paragraphs. Refer to APPENDIX B and APPENDIX C to see the placement of the formatted data in the input file and to see the data in a more easily interpreted form in the output file, respectively. Refer to Ref. [1] for the structure and variable names that are used in the ATB program.

##### **a. Planar contact surfaces**

The data defining each of the contact planes is placed on cards D.1 and D.2.a through D.2.d. Card D.1 lists the number of planes, simple belts, airbags, contact (hyper) ellipsoids, etc. Card D.2.a list the plane identification number and a 20-character

description of the plane. Cards D.2.b, c, and d list the (x,y,z) coordinates of points P1, P2, and P3, respectively. These coordinates are referenced to the local coordinate system of whatever segment to which the planes are attached. In this example, all planes are attached to the vehicle and the vehicle local coordinate system is coincident with the inertial coordinate system. Figure 44 shows the D.1 card along with the D.2 cards for plane number one, the seat bottom (cushion).

Number of Planes									
9	1	0	0	0	0	0	0	7	0
CARD D.1									
1	Seat	Cushion.	Bottom.	Plane Description					
	-9.5		-9.25	-24.5	P1 (x,y,z)				
	-9.5		9.25	-24.5	P2 (x,y,z)				
	9.5		-9.25	-24.5	P3 (x,y,z)				
Plane Number									

**Figure 44. Planar Contact Surface Formatting.**

#### **b. Armrests**

There is a difference between a segment and a contact (hyper) ellipsoid. When a segment is defined, a contact ellipsoid is associated with it. This data is defined in the B Cards as was seen in APPENDIX E for the body data set. Additional contact (hyper) ellipsoids may be defined in much the same way the planar contact surfaces are defined, with the data being entered on Cards D.5. In this example problem, the armrests are defined to be segments (thus possessing mass and inertial properties) and have contact ellipsoids associated with them. This means that the data for the armrests will be entered with the remainder of the body segments on the B Cards.

The number of segments and number of joints, along with a 20-character description of the crash victim, are entered on Card B.1. For each segment, Card B.2.a contains the four-character abbreviation, weight, principal moments of inertia, contact ellipsoid semi-axis lengths and offset values, and a flag alerting whether or not the principal axes are rotated. If the principal axes are rotated with respect to the local coordinate system, then the yaw, pitch, and roll angles are specified on Card B.2.b. For the armrests, segments 18 and 19, the B.2 cards are shown in Figure 45.

In addition to formatting the parameters for the armrest segments, it is necessary to format the data for the joints connecting the armrests to the vehicle. Each joint has its data specified on Cards B.3.a-b, B.4, and B.5. On Card B.3.a, the abbreviation, value for JNT (see Figure 30), joint type, and joint center location in both segment's coordinates are specified. On Card B.3.b, the orientation of the joint axes with respect to the segment local axes is specified. The torsional spring characteristics of the joint are specified on Card B.4 and the viscous and coulomb friction characteristics are specified on Card B.5. The formatted data for the joints connecting the armrests to the vehicle is shown in Figure 46. Although not shown, a Card B.6 is required for each joint.

This card controls the convergence criteria and can generally be copied from the B.6 cards for the other joints.

Abbreviation		Weight		Ellipsoid Semi-axis Lengths (x,y,z)			0 - Principle axes not rotated			
LAR	8	2.000	.0850 .0022 .0863	1.000	7.000	.5000	.000	.000	.000	0 CARD B.2
RAR	9	2.000	.0850 .0022 .0863	1.000	7.000	.5000	.000	.000	.000	0 CARD B.2

Principle Moments Of Inertia (x,y,z)

Center of Ellipsoid Offset (x,y,z)

Figure 45. Armrest Segment Data Formatting.

Abbreviation		JNT (20 = Vehicle)		Joint Center Location (x,y,z) in Vehicle Coord.			Joint Center Location (x,y,z) in Armrest Coord.			
LR	20	1	10.50-10.00-31.75	.00	-6.50	.00	0	.00	.00	CARD B.3
			90.00 .00 .00	90.00-48.50	.00	.00	.00	.00	.00	0 0 0 0 0 0
RR	20	1	10.50-10.00-31.75	.00	-6.50	.00	0	.00	.00	CARD B.3
			90.00 .00 .00	90.00-48.50	.00	.00	.00	.00	.00	0 0 0 0 0 0

Joint Type (1 = pin)

Joint Axes Rotation (yaw, pitch, roll) wrt Vehicle Coord.

Joint Axes Rotation (yaw, pitch, roll) wrt Armrest Coord.

---

Energy Dissipation (1 = No Loss)

.00150.00	.00	1.00	48.50	.00	.00	.00	1.00	.00	CARD B.4
.00150.00	.00	1.00	48.50	.00	.00	.00	1.00	.00	CARD B.4

Linear, Quadratic, Cubic Spring Coeff. (0.0, 150.0, 0.0)

Joint Stop Angle

---

Viscous Coefficient

.0001	0.	30.	0.	0.	0.	0.	0.	CARD B.5
.0001	0.	30.	0.	0.	0.	0.	0.	CARD B.5

Relative Velocity Above Which Full Coulomb Friction Applied

Coulomb Friction Coefficient

Figure 46. Armrest Joint Data Formatting.



### c. Lap belt

The lap belt data is the final portion of the environmental specification to be formatted (force-deflection characteristics are covered in the next section). The number of simple belts is specified on Card D.1 (second column, see Figure 44), the 20 character description and the coordinates of the anchor points are specified on Cards D.3.a and D.3.b, respectively, and the coordinates of the segment contact point and the initial slack are specified on Card D.3.c. The formatted data for the lap belt is shown in Figure 47.

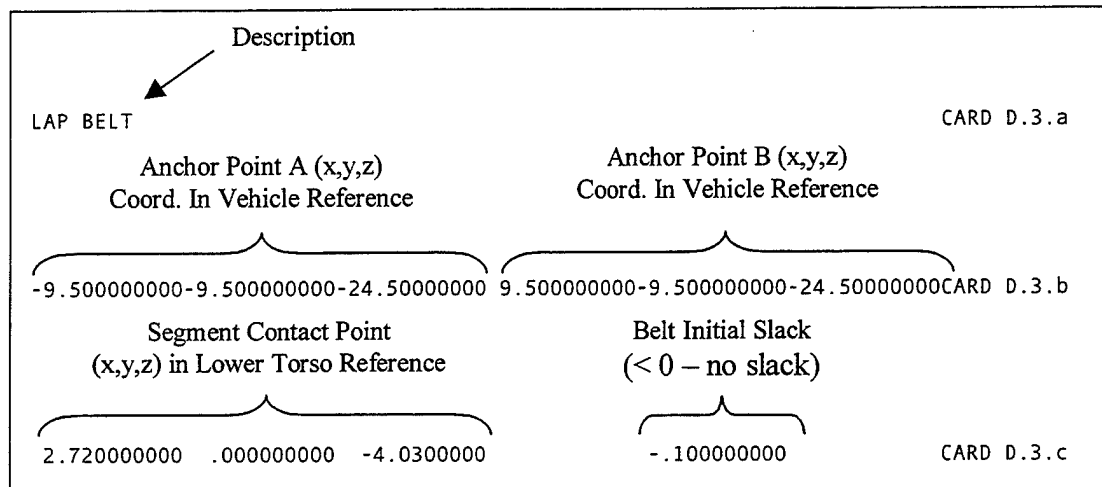


Figure 47. Lap Belt Data Formatting.

## C. DEFINING FORCE-DEFLECTION CHARACTERISTICS

Once the contact surfaces have been identified and laid out as described in the previous section, the manner in which the body segments interact with these surfaces must be defined. A systematic approach will help to ensure that no important interactions are overlooked.

### 1. Allowed Plane-Segment Contacts

For each previously identified plane, determine what body segments are likely to interact with it. As previously stated, there can be a maximum of five segments contacting a single plane. If more than five segments are expected to interact with a given surface, a duplicate plane can be defined. In addition, the total number of plane-segment contacts must be less than 70. Use of a table to lay out the allowed plane-segment contacts makes it easy to verify that neither limit is exceeded.

By examining the videotape of the actual test, it was estimated that the only plane-segment contacts that would be required are those detailed in Table 10. Note that not all planes that were previously identified have contacts specified. This is completely acceptable and by defining the planes in the input deck, they will be rendered in the visualization. In order to verify that the assumptions were adequate and that no important interactions were excluded, the visualization (either using VIEW or IMAGE) can be examined once the simulation has been performed. If, during this examination, a segment is seen to pass through a plane, then that plane-segment contact should be

allowed. This is most easily done using the IMAGE program, which allows for changing the viewing angles while the simulation is playing.

**Table 10. Allowed Plane-Segment Contacts.**

Plane #	Plane ID	# of Contacts	Segment #	Segment ID
1	Seat Cushion. Bottom.	3	1	Lower Torso
			6	Right Upper Leg
			9	Left Upper Leg
2	Seat Cushion. Front.	2	7	Right Lower Leg
			10	Left Lower Leg
5	Seat Back.	5	1	Lower Torso
			2	Middle Torso
			3	Upper Torso
			12	Right Upper Arm
			14	Left Upper Arm
6	Seat Back. Top.	2	4	Neck
			5	Head
7	Seat Back. Right Side.	2	12	Right Upper Arm
			13	Right Lower Arm
8	Seat Back. Left Side	2	15	Left Upper Arm
			14	Left Lower Arm
9	Deck.	2	8	Right Foot
			11	Left Foot
Total Number of Contacts		18		

## 2. Allowed Segment-Segment Contacts

As was the case for identifying plane-segment contacts, constructing a table helps to systematically identify what segment-segment contacts are to be allowed and to verify that no limits are exceeded. Again, there is a limit of five contacts per segment. The total number of segment-segment contacts is limited to 40 vice 70 as for plane-segment contacts.

Viewing the videotape of the actual test led to the list of allowed segment-segment contacts detailed in Table 11. Note that contacts can be specified in either order. For example, segment 16 (Right Hand) can be specified as a segment allowed to contact segment 1 (Lower Torso), or segment 1 can be specified as a segment allowed to contact segment 16. This flexibility helps avoid problems with having more than five contacts specified for any given segment.

As for the plane-segment contacts, the assumptions that were made can be verified by examining the visualization (easiest to do using IMAGE) for any segments that appear to pass through another segment.

**Table 11. Allowed Segment-Segment Contacts.**

Seg. #	Segment ID	# of Contacts	Seg. #	Segment ID
1	Lower Torso	4	13	Right Lower Arm
			15	Left Lower Arm
			16	Right Hand
			17	Left Hand
2	Middle Torso	4	6	Right Upper Leg
			9	Left Upper Leg
			16	Right Hand
			17	Left Hand
3	Upper Torso	4	6	Right Upper Leg
			9	Left Upper Leg
			13	Right Lower Arm
			15	Left Lower Arm
5	Head	4	13	Right Lower Arm
			15	Left Lower Arm
			16	Right Hand
			17	Left Hand
6	Right Upper Leg	5	9	Left Upper Leg
			12	Right Upper Arm
			13	Right Lower Arm
			16	Right Hand
			17	Left Hand
7	Right Lower Leg	2	10	Left Lower Leg
			11	Left Foot
9	Left Upper Leg	4	14	Left Upper Arm
			15	Left Lower Arm
			16	Right Hand
			17	Left Hand
10	Left Lower Leg	1	8	Right Foot
13	Right Lower Arm	3	2	Middle Torso
			15	Left Lower Arm
			17	Left Hand
15	Left Lower Arm	2	2	Middle Torso
			16	Right Hand
18	Left Armrest	3	3	Upper Torso
			14	Left Upper Arm
			15	Left Lower Arm
19	Right Armrest	3	3	Upper Torso
			12	Right Upper Arm
			13	Right Lower Arm
Total Number of Contacts		39		

### 3. Sources of Force-Deflection Data

Determining these characteristics for each allowed plane-segment or segment-segment contact can be a difficult and time-consuming process. Obviously, direct measurement of the characteristics will lead to the most accurate results in the simulation. Unfortunately, this may not always be possible or even desired. Time, availability, or funding constraints may preclude direct measurements, thus requiring the force-deflection characteristics be obtained in another fashion. One method is to use characteristics that have previously been defined for similar contacts. For example, the force-deflection characteristics for the seating surfaces in this example model were derived from the characteristics used in a model of an aircraft ejection seat.

For the ATD's, GEBOD provides several force-deflection functions for various contact surfaces as previously discussed. These functions can be used directly, or combined with additional functions, to characterize the interactions between segments and planes or segments and other segments. Alternatively, a general segment-segment characteristic can be defined to simplify the modeling process.

### 4. Defining the Functions

There are two categories of force-deflection characteristics as described in Chapter II. Rate-dependent characteristics, as illustrated in Figure 15, may be used, or characteristics dependent upon the deflection alone, as illustrated in Figure 17, may be used. In either case, functions defining the various components of the force-deflection characteristics must be defined as illustrated in Figure 16. As previously described, the functions can be constant, tabular, or polynomial, subject to the constraints detailed in Table 1.

The force-deflection characteristics for the planes making up the seat bottom (cushion, right side, left side, and front) as well as the sides for the seat back (right side, left side, and top) are shown in Figure 48. The seat back cushion itself has force-deflection characteristics as defined by the functions shown in Figure 49 and the characteristics for the deck are illustrated in Figure 50. As far as segment-segment contacts are concerned, a generic force-deflection characteristic was defined and was used for all body segment to body segment interactions. These characteristics functions are shown in Figure 51. The only other segment-segment interactions are body segment to armrest contacts and the characteristic functions are shown in Figure 52. Finally, the force-deflection characteristics for the lap belt are illustrated in Figure 53. The tabulated values used to generate these function curves are summarized in Table 12. These same values will be used in the input deck. Function 20, as seen in Figure 48, is defined as a polynomial such that  $F=200*x$ , where  $F$  is the force in pounds and  $x$  is the deflection in inches.

As previously mentioned, the force-deflection characteristics for the contacts in this example were not measured directly due to availability and funding constraints, but rather were derived from other example simulations (aircraft ejection seat, etc.). Note that the majority of the force-deflection characteristics were defined using the rate dependent functions, and only the deck and lap belt characteristics were defined using the functions dependent on deflection alone. Also, note that the base function for the lap belt has strain, vice deflection, as the abscissa.

In addition, for each allowed contact, there must be a friction function defined. In this example, all body segment to body segment contacts have a friction coefficient of 0.1 specified. All body segment to chair surface (planes and armrests) contacts have a friction coefficient of 0.9 specified. For the lap belt to lower torso contact, there are only two friction options (previously described) since a simple, vice harness, belt was chosen. In this example, full belt friction is specified so that the tension in each belt half is computed separately.

**Table 12. Summary of Function Values**

Function #	# of Point								
14	5	abscissa	0.000	1.000	2.000	3.000	4.000		
		ordinate	0.000	60.000	200.000	800.000	2000.000		
21	21	abscissa	-40.000	-30.000	-20.000	-10.000	0.000	5.000	10.000
		ordinate	0.000	0.000	0.000	0.000	0.000	1.000	1.000
		abscissa	20.000	30.000	40.000	50.000	60.000	70.000	80.000
		ordinate	0.990	0.965	0.930	0.860	0.690	0.475	0.340
		abscissa	90.000	100.000	110.000	120.000	130.000	140.000	150.000
		ordinate	0.260	0.200	0.180	0.090	0.060	0.025	0.000
24	6	abscissa	0.000	0.010	0.020	0.030	0.050	0.100	
		ordinate	0.000	165.000	330.000	495.000	935.000	3850.000	
25	8	abscissa	0.000	0.200	0.401	0.603	0.803	0.834	0.930
		ordinate	0.000	6.750	25.290	48.720	101.790	121.200	1212.000
		abscissa	1.354						
		ordinate	12120.000						
27	6	abscissa	0.000	0.100	0.200	1.000	2.000	3.000	
		ordinate	0.000	100.000	1000.000	5000.000	10000.000	15000.000	
28	6	abscissa	0.000	1.000	2.000	3.000	4.000	6.000	
		ordinate	0.000	60.000	150.000	500.000	2000.000	10000.000	
29	6	abscissa	0.000	1.000	2.000	3.000	4.000	6.000	
		ordinate	0.000	50.000	125.000	250.000	500.000	1000.000	
30	5	abscissa	-1000.000	-6.000	-5.000	0.000	1000.000		
		ordinate	0.500	0.500	1.000	1.000	1.000		
31	5	abscissa	-2000.000	-200.000	0.000	200.000	2000.000		
		ordinate	0.000	0.000	0.000	10.000	200.000		
34	6	abscissa	0.000	0.500	1.000	1.500	1.800	2.000	
		ordinate	0.000	30.000	60.000	90.000	900.000	9000.000	
35	5	abscissa	-1000.000	-6.000	-5.000	0.000	1000.000		
		ordinate	0.460	0.460	1.000	1.000	1.000		
36	5	abscissa	-2000.000	-200.000	0.000	200.000	2000.000		
		ordinate	0.000	0.000	0.000	50.000	1000.000		

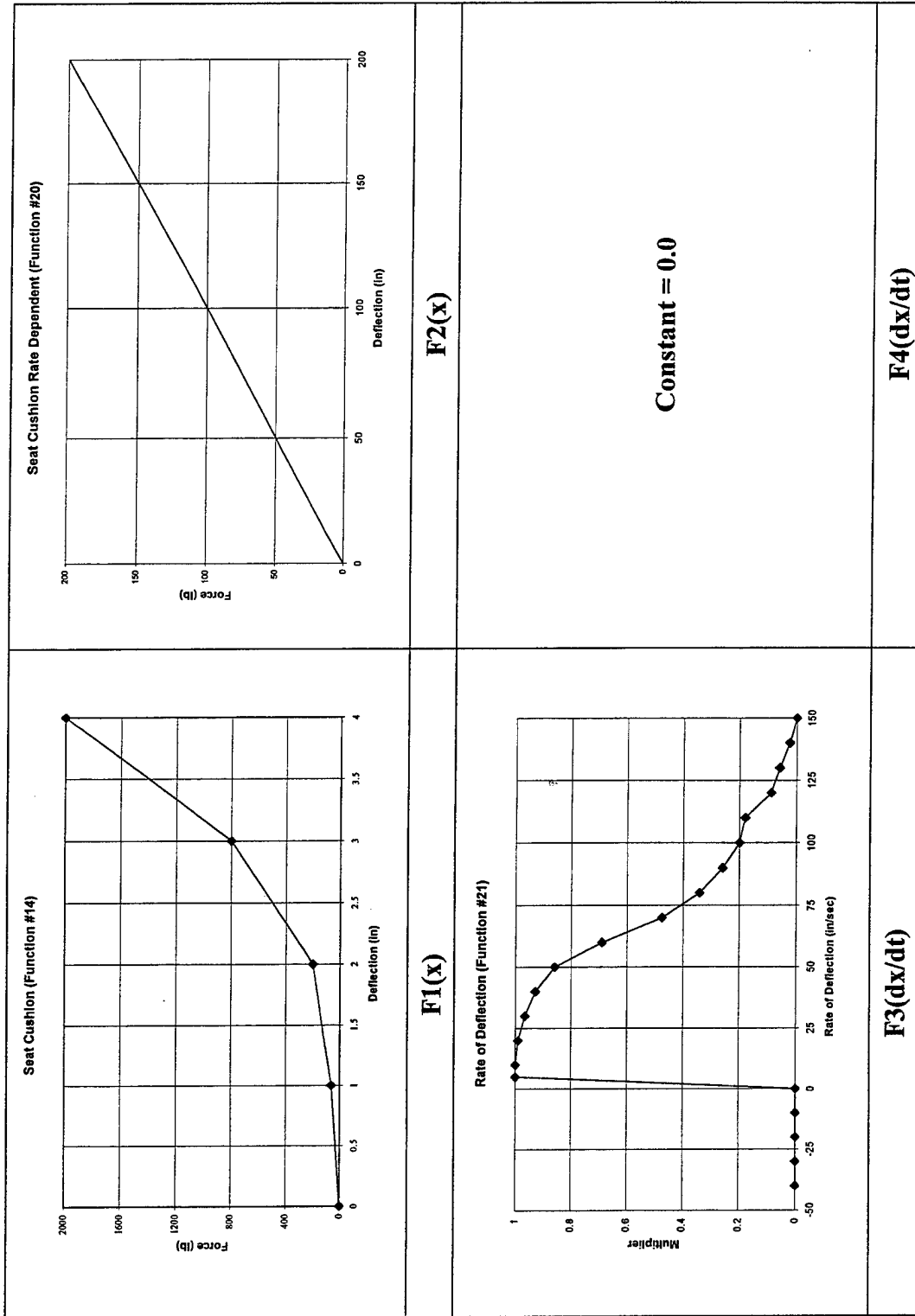


Figure 48. Seat Cushion Force-Deflection Characteristics.

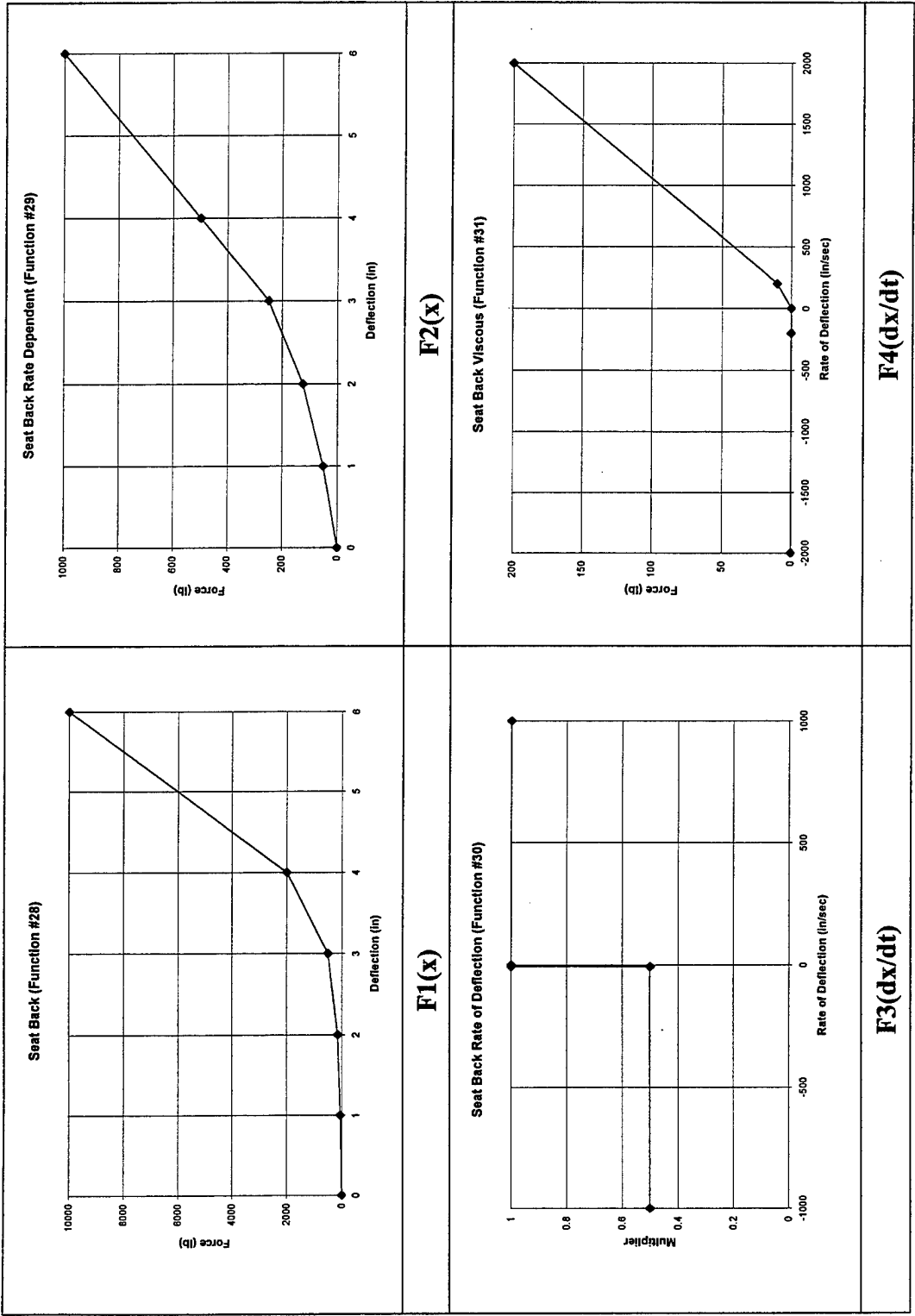


Figure 49. Seat Back Force Deflection Characteristics.

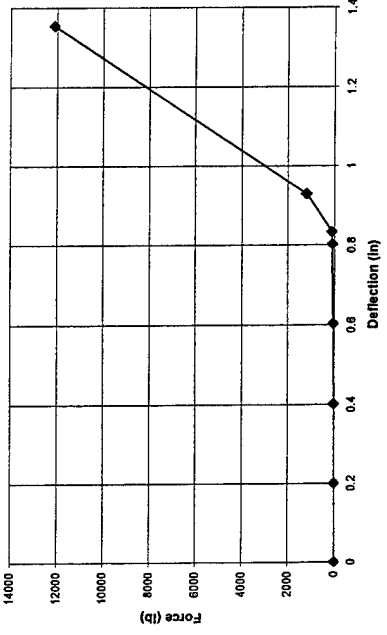
<p style="text-align: center;"><b>Deck (Function #25)</b></p>  <p style="text-align: center;"><b>Constant = 0.0</b></p>	<p style="text-align: center;"><b>Inertial Spike Function</b></p> <p style="text-align: center;"><b>Constant = 0.0</b></p>
<p style="text-align: center;"><b>Base Function</b></p> <p style="text-align: center;"><b>Constant = 1.0</b></p>	<p style="text-align: center;"><b>Energy Absorption Factor Function</b></p> <p style="text-align: center;"><b>Permanent Deflection Factor Function</b></p>

Figure 50. Deck Force-Deflection Characteristics.



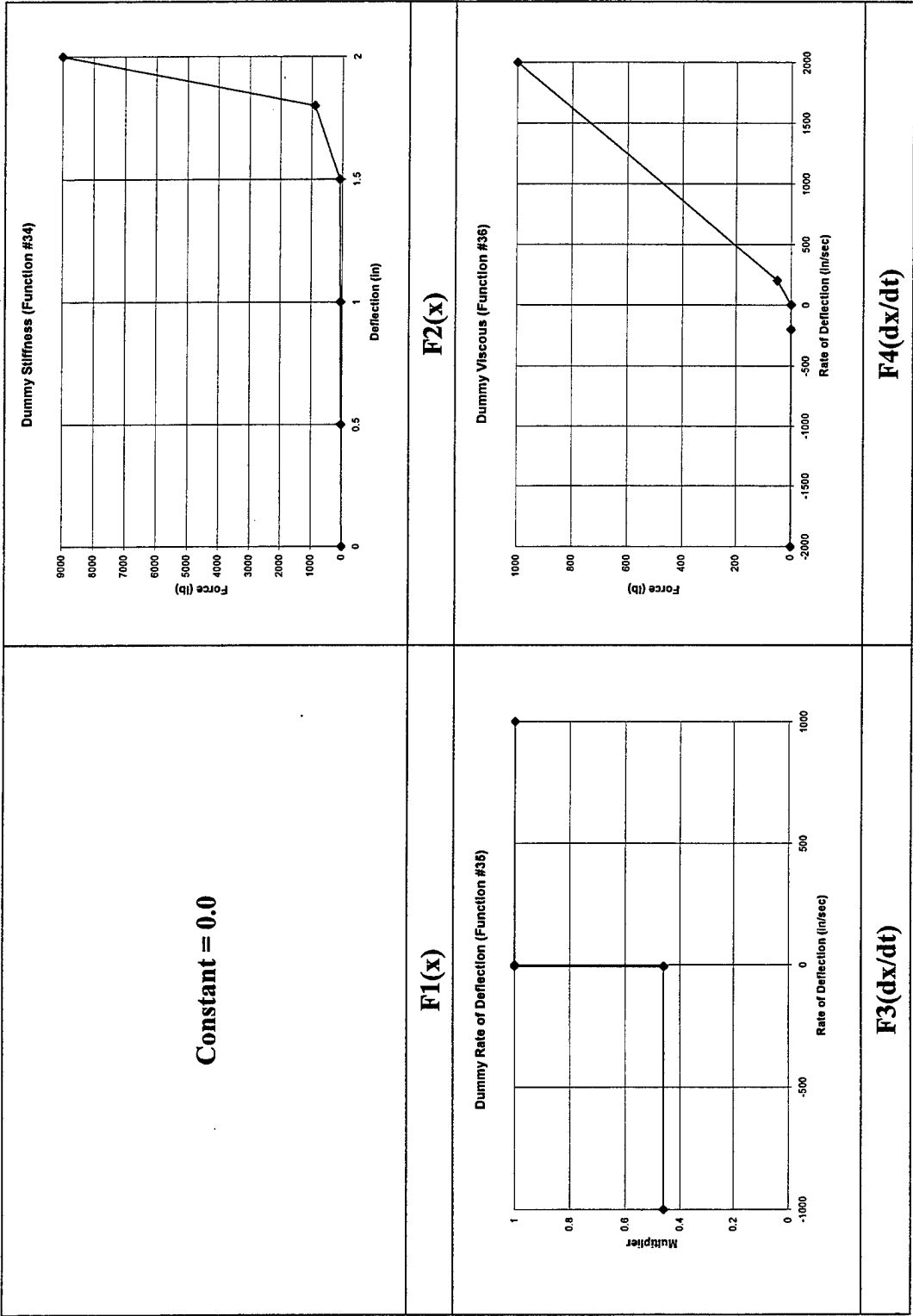


Figure 51. Dummy Force-Deflection Characteristics.

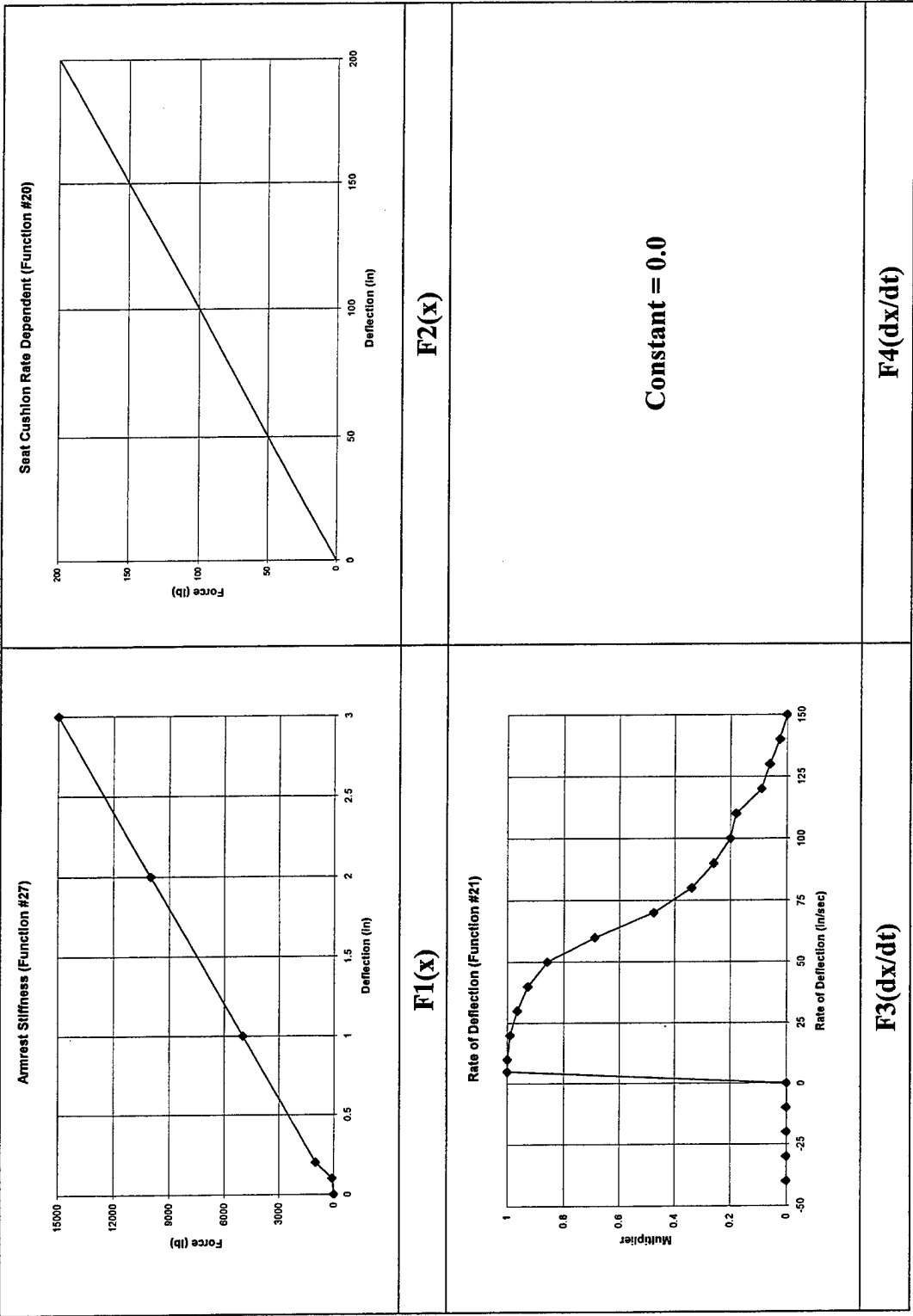


Figure 52. Armrest Force-Deflection Characteristics.

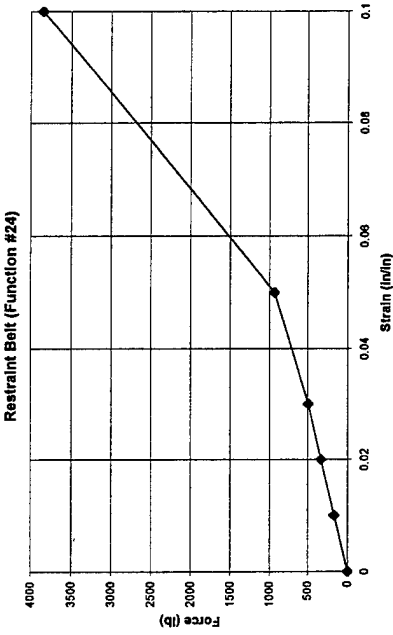
<p>Restraint Belt (Function #24)</p> 	<p>Constant = 0.0</p>
<p>Base Function</p> <p>Constant = 1.0</p>	<p>Inertial Spike Function</p> <p>Constant = 0.0</p>
<p>Energy Absorption Factor Function</p>	<p>Permanent Deflection Factor Function</p>

Figure 53. Lap Belt Force-Deflection Characteristics.

### 5. Combining Functions

If the force-deflection characteristics for two elements, e.g., the deck plating and the foot of the Hybrid III dummy, are known, then these two functions can be combined to yield a single function that can then be used for contacts between those two elements. This is the method used to generate the deck-foot force-deflection function illustrated in Figure 50.

The procedure is much like that used to determine an effective spring constant for two springs in series. Each spring is subjected to the same force, thus deflects an amount determined by its own spring constant, and the total deflection for the given applied force is simply the sum of the deflections. Analogously, the foot and the deck both experience the same force, and the deflections of each element required to generate that force are based upon their respective force-deflection characteristics. To generate a composite force-deflection characteristic, the deflections of each element for a given force are simply added.

The GEBOD program provides a force-deflection characteristic for the feet of the 50<sup>th</sup> percentile male Hybrid III dummy as a composite polynomial and tabular function. The polynomial portion of the foot force-deflection function is given by Equation (6) and the tabular portion is detailed in Table 13. The deck surface was simply assumed to have a stiffness of 30,000 lb/in.

$$\begin{aligned} F(x) = & -0.68 + 82.75x - 704.17x^2 + 3367.10x^3 \\ & - 5570.69x^4 + 3188.30x^5 \end{aligned} \quad (6)$$

*for  $0 \leq x \leq 0.83$*

**Table 13. Tabular Portion of Foot Force-Deflection Characteristic.**

Deflection (in)	Force (lb)
0.83	121.20
0.89	1212.00
0.95	12120.00
<i>Valid for <math>x &gt; 0.83</math> inches</i>	

To create a combined force-deflection function (in tabular form), the polynomial portion of the foot force-deflection function was first converted to a tabular form by evaluating the polynomial at several deflections. Then, the deflection of the deck was computed for each of the forces determined from the foot force-deflection characteristic at the specified deflections. These two deflections were then added at each force level to create the combined foot-deck contact force-deflection characteristics. These values are detailed in Table 14.

**Table 14. Combined Foot-Deck Force-Deflection Function Values.**

<b>Force (lb)</b>	<b>Foot Deflection (in)</b>	<b>Associated Deck Deflection (in)</b>	<b>Sum of Deflections (in)</b>
0.00	0.00	0.0000	0.000
6.75	0.20	0.0002	0.200
25.29	0.40	0.0008	0.401
48.72	0.60	0.0016	0.602
101.79	0.80	0.0030	0.803
121.20	0.83	0.0040	0.834
1212.00	0.89	0.0404	0.930
12120.00	0.95	0.4040	1.354

## **6. Formatting the Data**

As was the case for the definitions of the environmental elements, the data for the allowed contacts, and the functions they are used to make up the force-deflection characteristics of those contacts, must be transformed into the proper ATB format in accordance with Ref. [1]. The following paragraphs describe the manner in which the data for the functions and the allowed plane-segment, segment-segment, and lap belt-segment contacts are formatted.

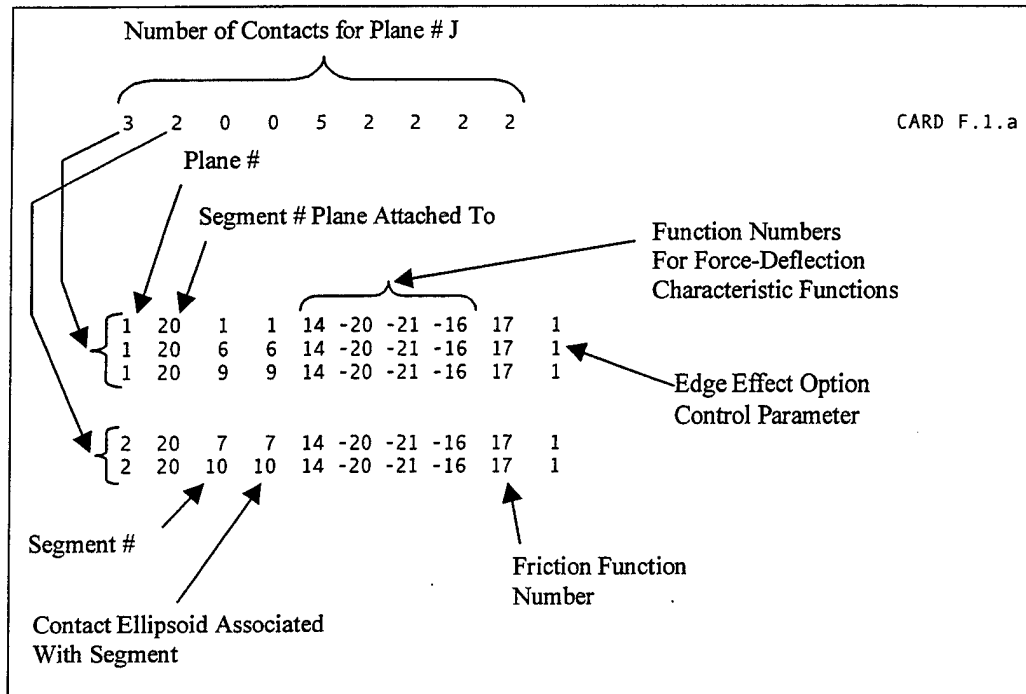
### **a. Allowed contacts**

All data pertaining to the allowed contacts is specified on the F Cards. Card F.1.a lists the number of contacts that are allowed for each specified plane. Then, for each plane that has contacts allowed, one F.1.b card must be provided per contact. Each of these F.1.b cards contains the plane number, the segment number to which the plane is attached, the segment number for which contact is allowed, the number of the contact ellipsoid associated with that segment, the function numbers defining the force-deflection characteristics, the friction function number, and an edge effect control parameter. A portion of the formatted data for the plane-segment contacts is shown in Figure 54.

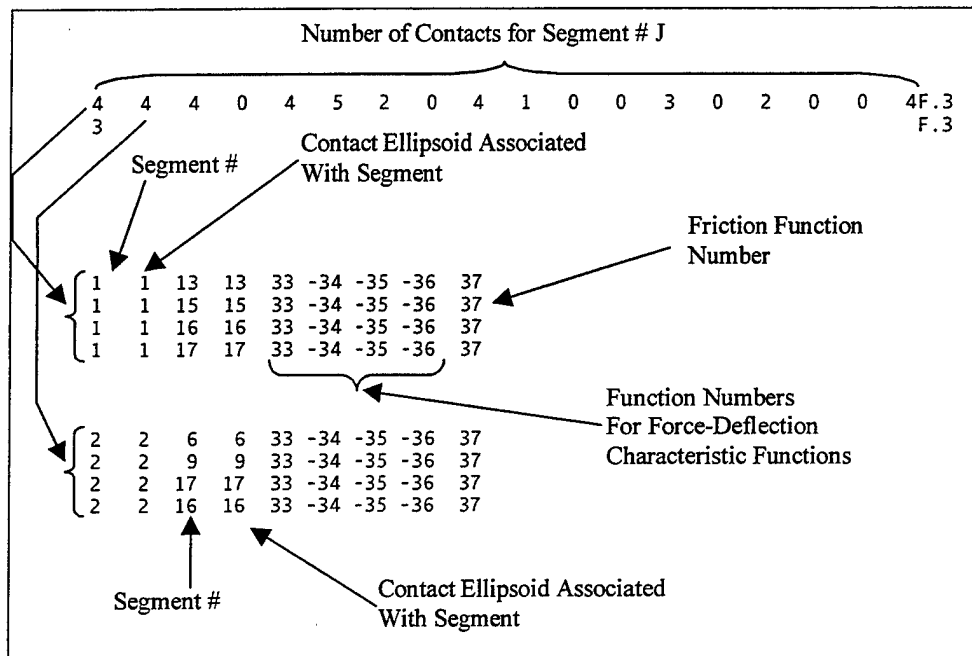
Segment-segment contact data is similarly specified, although there is no edge effect option control parameter for segment-segment contacts. The number of contacts allowed for each segment is specified on Card F.3.a. Then, for each segment that has contacts allowed, one F.3.b card must be provided per contact. Each of these F.3.b cards contains the segment number, the number of the associated contact ellipsoid, the segment number for which contact is allowed, the number of the contact ellipsoid associated with that segment, the function numbers defining the force-deflection characteristics, and the friction function number. A portion of the formatted segment-segment contact data is shown in Figure 55.

The contact information for simple belts is also formatted in a manner similar to the plane-segment and segment-segment contact information. Card F.2.a lists the number of segments each belt can interact with (note that this can be only zero or one). Then, for each belt that has an allowed contact, a Card F.2.b must be specified. This card contains the belt number, the segment number to which the belt is attached, the

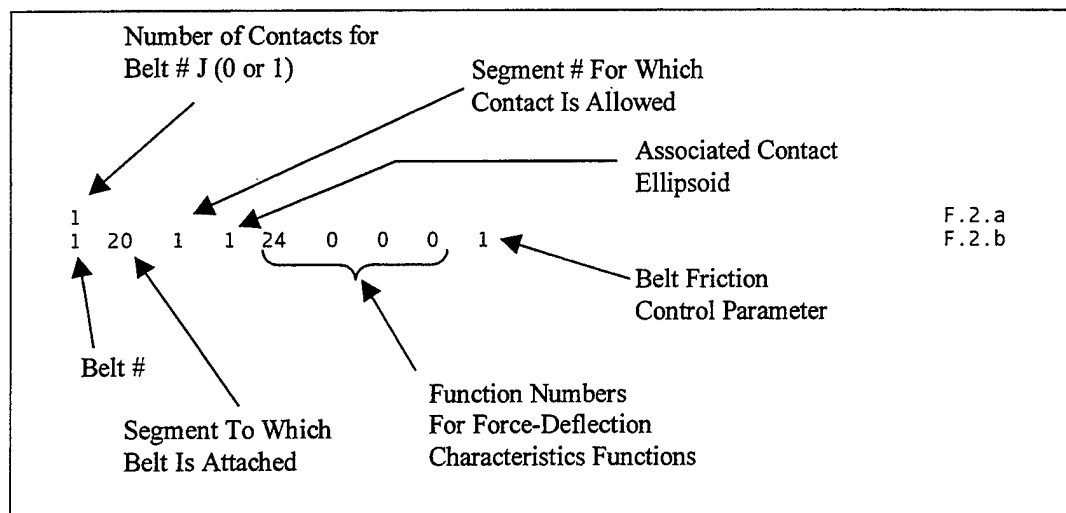
number of the segment with which contact is allowed, the number of the contact ellipsoid associated with that segment, the force-deflection characteristic function numbers, and a belt friction control parameter. The formatted data for the lap belt (contact with lower torso) is shown in Figure 56.



**Figure 54. Plane-Segment Contact Data Formatting.**



**Figure 55. Segment-Segment Contact Data Formatting.**



**Figure 56. Lap Belt Contact Data Formatting.**

### **b. Functions**

Each of the functions that have been identified in the sections above must have their defining data properly formatted. The E Cards contain the data defining all of the force-deflection, inertial spike, energy absorption factor, and friction coefficient functions. Each function has an E.1 card that contains the function identifying number and a 20-character description. This is followed by an E.2 card containing significant points on the abscissa, including D0, D1, and D2 as shown in Figure 16 and Table 1. Then, if the function is a polynomial, the five coefficients are specified on Card E.3. If the function is tabular, then Card E.4.a list the number of pairs of data points that make up the table, and these pairs are specified on Cards E.4.b (three pairs per card). The formatted data for the force-deflection function, F1, for the foot-deck contact is shown in Figure 57. If a constant value is to be specified for a function, then only Cards E.1 and E.2 are required. Card E.1 is the same as described above, and for Card E.2, the values of D0 and D1 are specified to be zero while the value of the function (constant) is specified in field D2.

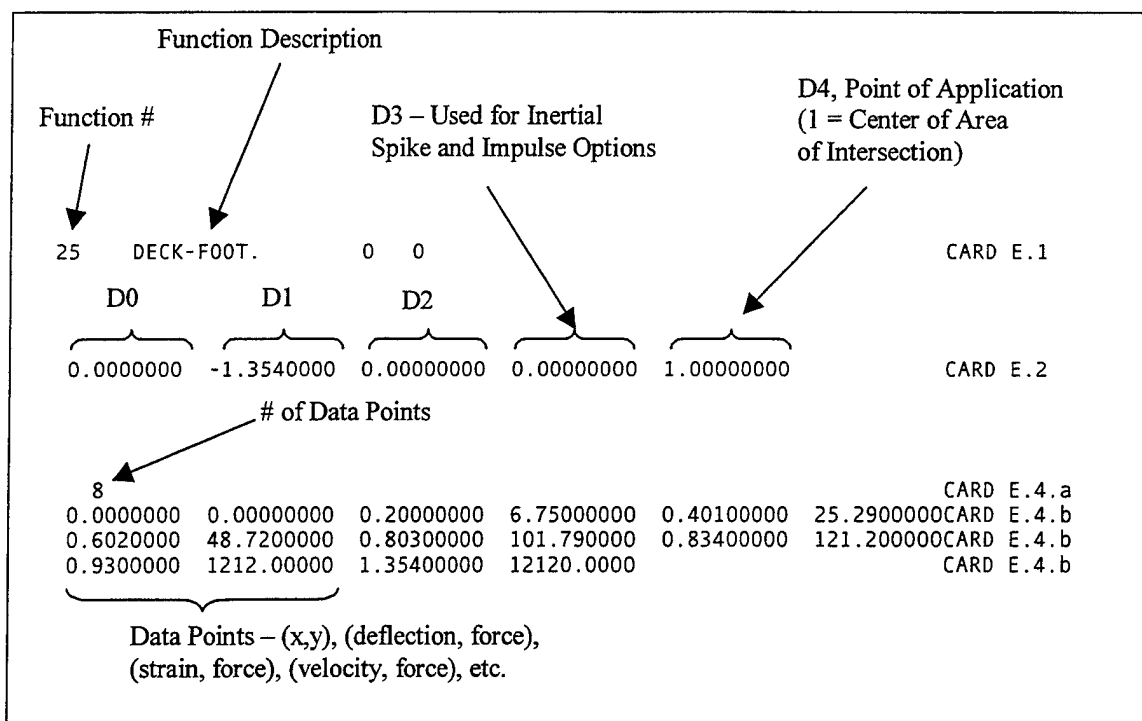


Figure 57. Function Data Formatting.

## D. VEHICLE EXCITATION

The specification of vehicle excitation is another major component of the input deck. Of the four previously described methods by which the vehicle motion can be specified, the six-degree-of-freedom tabular deceleration was the most appropriate for this example problem since accelerometer data was available.

### 1. Pre-Processing Input Data

Only with careful forethought can the necessity to pre-process excitation data measured during an actual test be eliminated. In this example, the deck vertical and athwartships accelerations were measured at the base of the chair and the fore-and-aft accelerations were measured at the forward end of the test vessel. No angular acceleration measurements were made during the test. The locations (and associated orientations) for which accelerometer data was available are shown in Figure 37.

The vertical and athwartships accelerations (A5051V and A5052A, respectively) could be used with only minor transformations since they were measured at the base of the operator's chair. First, the athwartships and vertical orientations from the test vessel must be transformed into the vehicle local coordinate system as described in Table 4. Then, since the vehicle excitation is to be specified as a deceleration vice acceleration, as previously stated, an additional factor of negative one must be included. The final conversion of measured acceleration to input deceleration is summarized in Table 15.

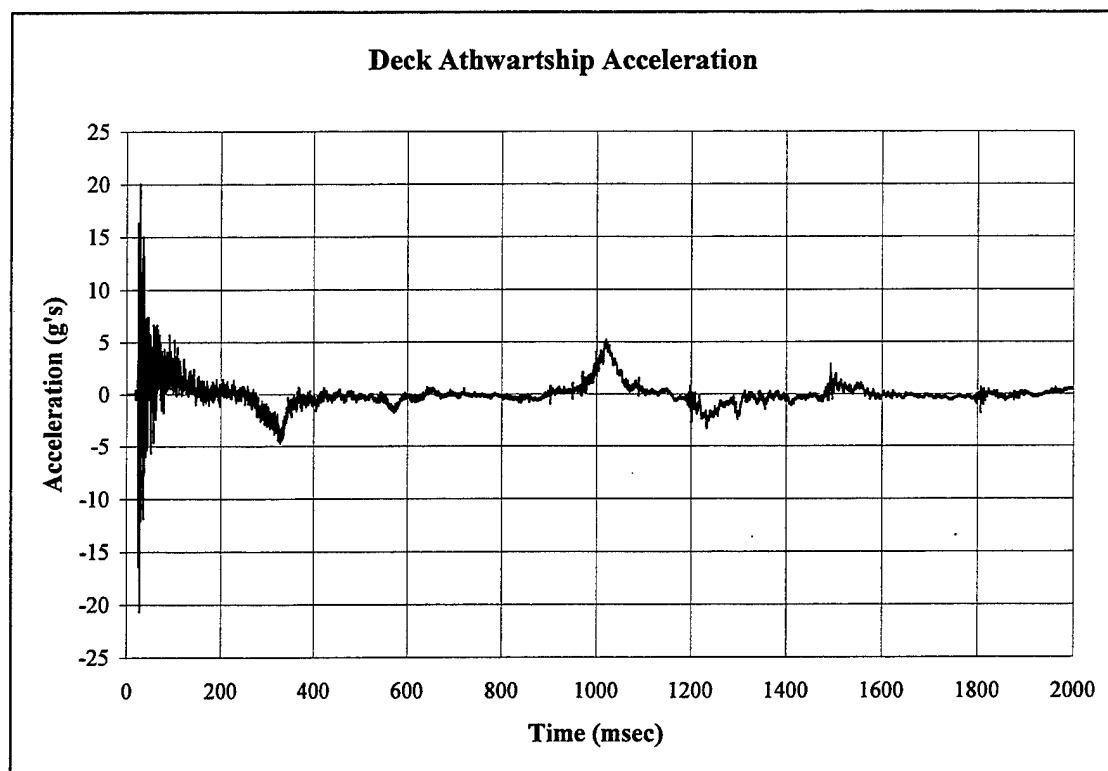
Figure 58 shows the measured acceleration of the deck in the athwartships direction (same as deceleration in the vehicle Y-axis). Figure 59 shows the measured acceleration of the deck in the vertical direction (same as deceleration in the vehicle Z-axis). The excitation of the deck in the fore-and-aft direction was not measured at the

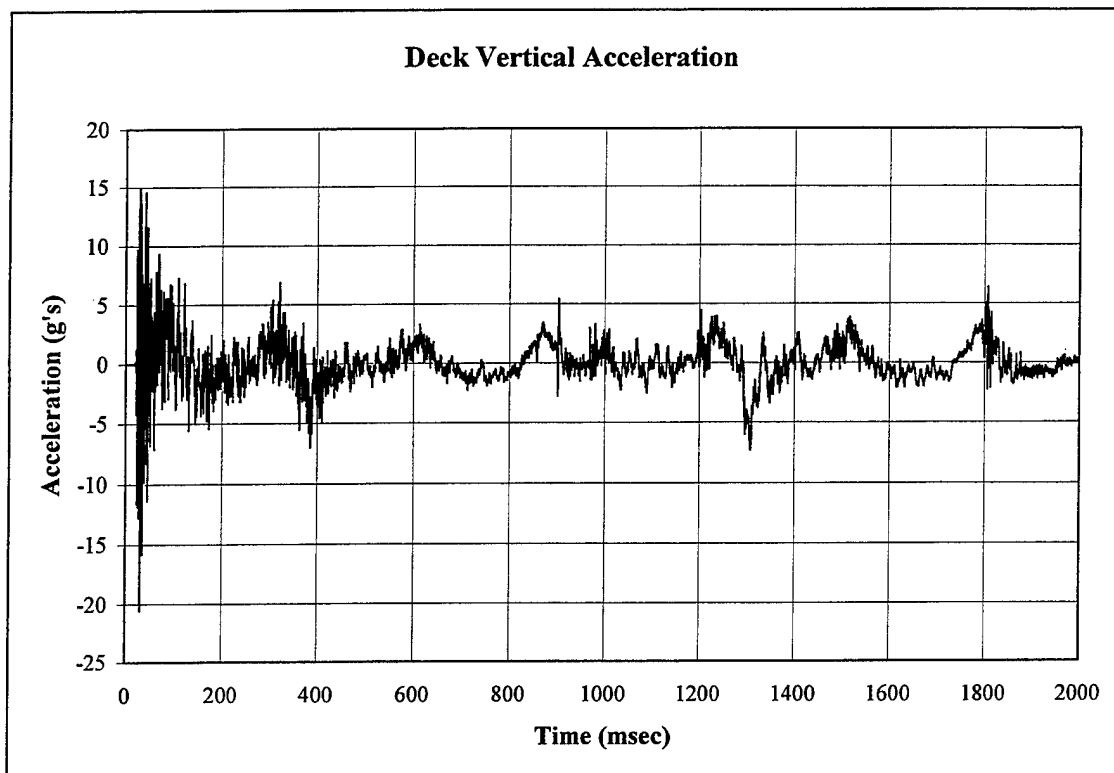


base of the operator's chair, as were the vertical and athwartships components. Rather, there were accelerometers oriented in the fore-and-aft direction located at either side of the forward end of the deck (A5003F and A5008F in Figure 37). This component of the excitation was of significantly lower amplitude than either the vertical or the athwartships components. In addition, the fore-and-aft orientation is perpendicular to the plane in which motion of the test subject predominantly occurred, as determined through close examination of the videotape. Thus, the fore-and-aft component of the acceleration was not included in the vehicle excitation

**Table 15. Measured Acceleration to Input Deceleration Conversion.**

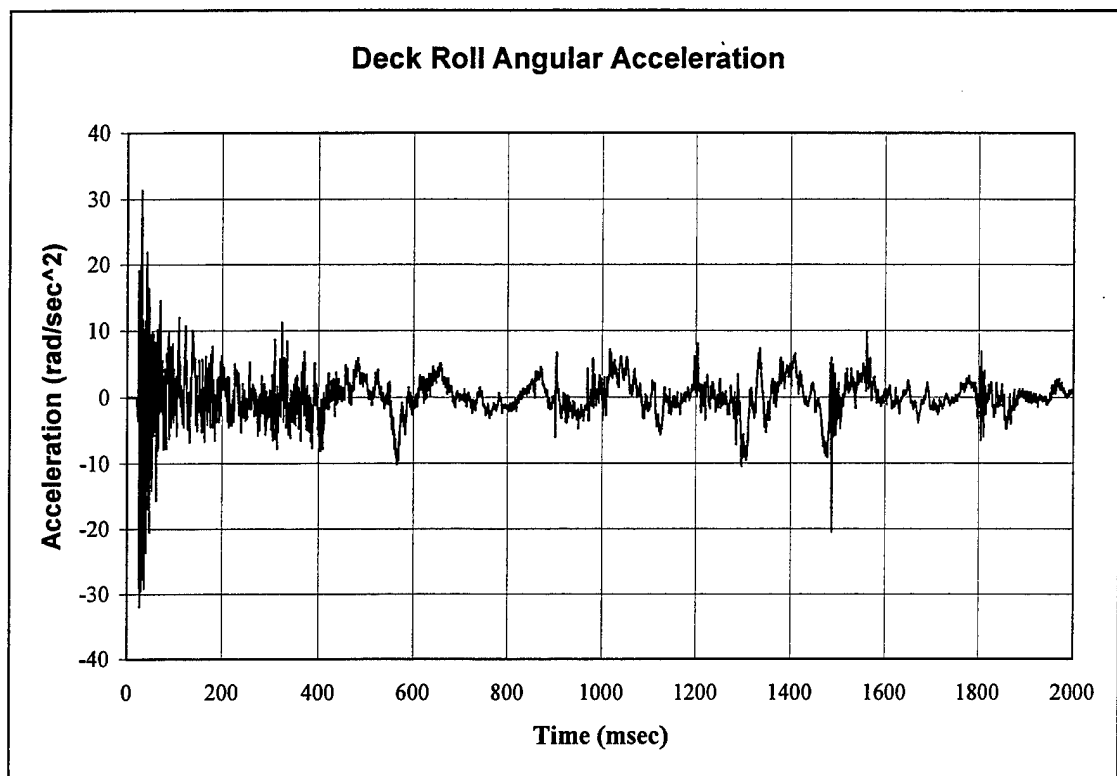
Measure Acceleration Direction	Multiplier	Input Deceleration Direction
Fore-and-Aft	-1	X
Athwartships	+1	Y
Vertical	+1	Z



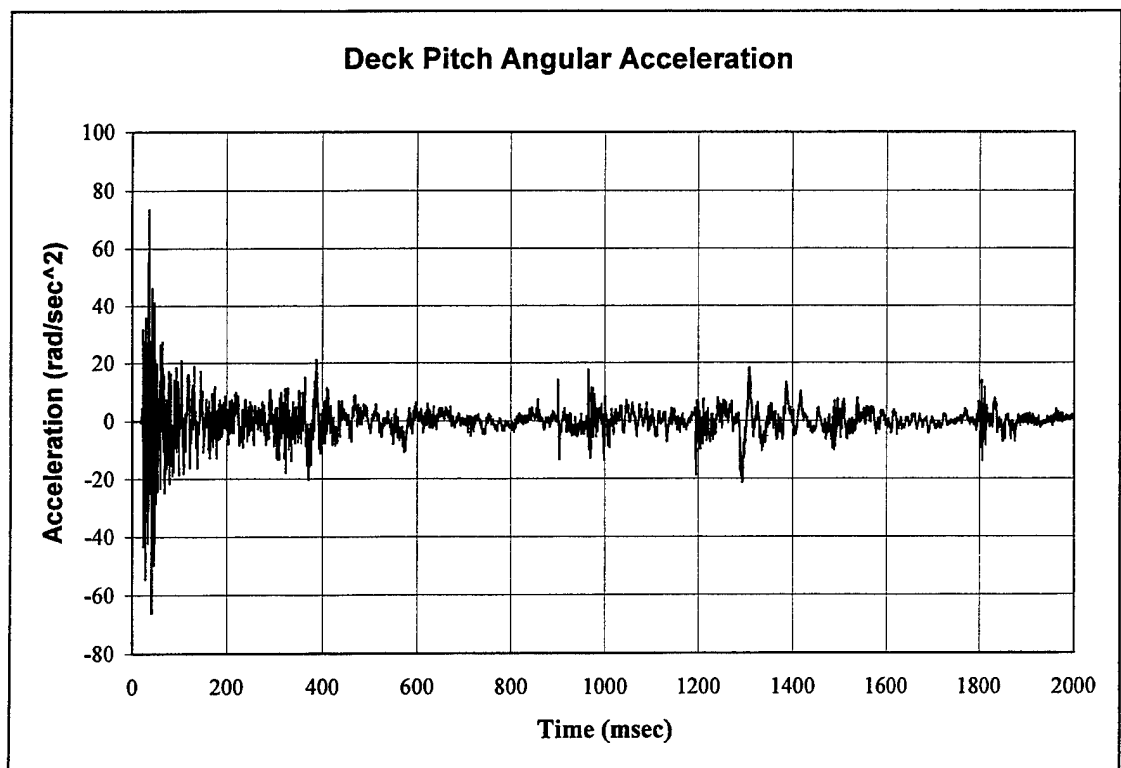


**Figure 59. Deck Vertical Acceleration.**

Since no deck angular acceleration measurements were made during the test, and these accelerations were expected to be significant, some method must be devised to estimate their values. As accelerometer data was available for all of the accelerometers shown in Figure 37, angular acceleration estimates were constructed from sets of two linear accelerometers oriented in the same direction, but separated by a distance. The roll angular acceleration was constructed from the data recorded using accelerometers A5018V (starboard side of test vessel near ATD) and A5011V (port side of test vessel near ATD). The acceleration values recorded with A5018V were subtracted from those recorded with A5011V, thus making A5018V (starboard side of test vessel) the reference. Then this value was divided by the linear distance separating the two accelerometers (roughly 30 feet). This value representing the angular acceleration about the longitudinal axis of the test vessel (the X-axis of the vehicle), but the units are g's per foot. Multiplication by  $32.2 \text{ ft}/(\text{sec}^2 \text{ g})$  and by  $57.3 \text{ degree/radian}$  yields the desired units (as required by the ATB program) of  $\text{deg}/\text{sec}^2$ . The deck pitch acceleration is computed in a similar manner using accelerometers A5051V (base of the operator's chair) and A5015V (aft end of test vessel near ATD) and a separation distance of ten feet. The roll and pitch angular accelerations derived using this method are shown in Figure 60 and Figure 61, respectively. The deck yaw angular acceleration, similarly derived, was of significantly lower magnitude and subsequently not included in the vehicle excitation.



**Figure 60. Deck Roll Angular Acceleration.**



**Figure 61. Deck Pitch Angular Acceleration.**

Finally, as was the case with the linear accelerations, the angular accelerations must be transformed into the vehicle coordinates and converted into decelerations. The coordinate systems were defined such that the vehicle's X-axis was aligned with the test vessel's longitudinal axis. Thus, positive angular accelerations about the test vessel's longitudinal axis need only be multiplied by a negative one to yield positive decelerations about the vehicle's X-axis. The pitch component was defined by referencing the accelerations at the base of the operator's chair to those at the aft end of the test vessel. Thus, positive pitch values defined in this manner correspond to negative values about the test vessel's transverse axis and to positive values about the vehicle's Y-axis. Finally, to convert the derived pitch angular accelerations into decelerations, the values need only be multiplied by a negative one.

## **2. Formatting the Data**

Once the excitation data has been pre-processed so that all sign conventions have been observed, the accelerations have been converted to decelerations, and the correct units are in use, it is necessary to format the data for use in the ATB program. All vehicle excitation data is contained on the C Cards. Card C.1 consists of an 80-character description of the crash vehicle deceleration. Card C.2.a contains information concerning the orientation of the deceleration (or initial orientation of the vehicle), the initial velocity of the vehicle, the inertial coordinates of the vehicle coordinate system origin, the segment number associated with the vehicle, and time control data (start time, time step, number of points). If tabular six degree of freedom deceleration or spline fit deceleration options are chosen, then the type of data, degree of polynomial for the spline fit, number of points, and initial angular velocities are specified on Cards C.2.b. For the six degree-of-freedom option, chosen for this example, the six components of the deceleration vector at each time step are listed on individual C.4 cards. The first portion of the C Cards for the example problem is illustrated in Figure 62. Note that the ATB program has been modified to allow up to 10,001 data points instead of the original 501 points.

## **3. Use of a Formatting Code**

For problems where the vehicle excitation has been measured using accelerometers, as is the case in this example, the task of formatting this data in the manner required by the ATB program could be quite formidable. This is particularly the case if the ATB program has been modified to allow a larger number of data points. In these instances, it might be beneficial to create a program that takes the raw data and generates a properly formatted set of C cards. Such a program was written, in MATLAB, to generate the C cards used in the input deck of this example. The program file is included as APPENDIX F.

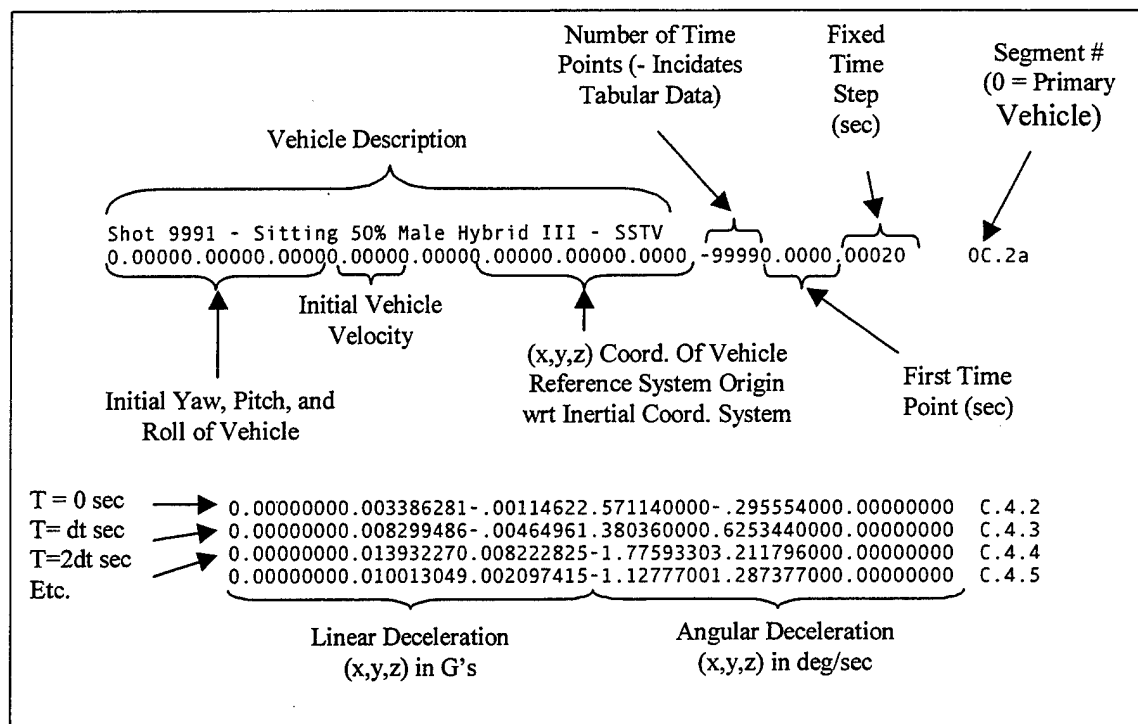


Figure 62. Vehicle Excitation Data Formatting.

## E. SPECIFYING DESIRED OUTPUT

The ATB program is capable of generating a tremendous amount of output data. If desired, tabulated time histories of plane-segment contact forces, segment-segment contact forces, belt tensions, body segment linear or angular accelerations, displacements, or velocities, joint forces and torques, and more can be output by the ATB program. However, it is likely that only a few parameters will be of interest. This section explores how to control what data is output by the ATB program.

### 1. Data for Troubleshooting and Establishing Equilibrium

The test subject or subjects must have their initial positions specified. The actual manner in which this specification is done will be covered in the next chapter, but some concerns about the applicable output will be addressed here.

To establish the initial equilibrium of a test subject, the forces exerted by gravity must be offset by some means. For a seated subject, as is the case in the example, these offsetting forces arise from interaction of the body segments with the contact surfaces of the chair. Evaluating the equilibrium of the body is done by checking the velocities and/or accelerations of the components. Troubleshooting problems with the initial equilibrium is done by examining the forces generated between the body segments and the contact surfaces of the chair. In addition, if any initial contact between body segments is specified, e.g., hands resting on upper legs, then the forces generated between the segments in question must be examined. Corrections are made by changing the initial positions of the body segments with respect to the chair and/or each other.

Tabular time histories of plane-segment or segment-segment contact forces may be generated to provide much of the necessary information for initial positioning of the

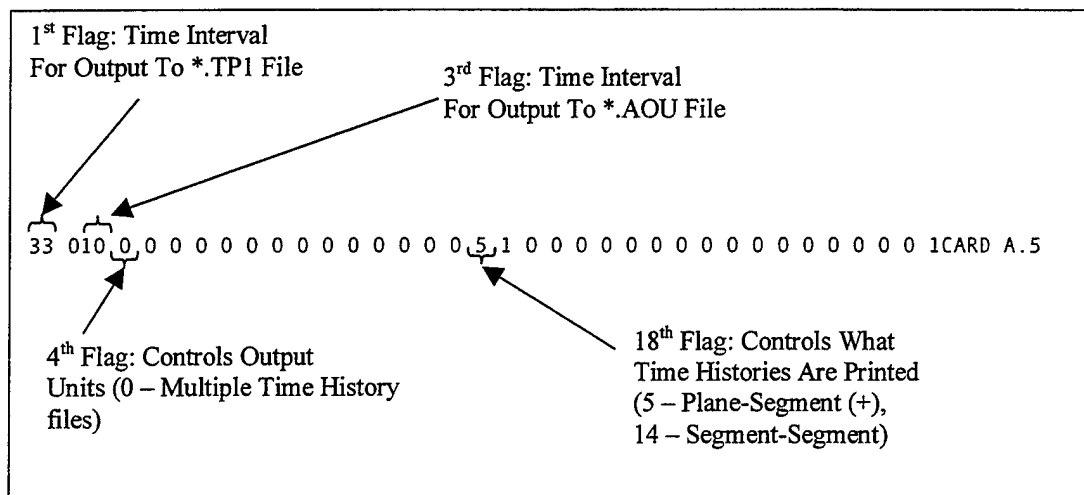
test subjects. To determine the accelerations and/or velocities of the body segments, there are two options. First, the tabular time histories of the accelerations, velocities, or displacements may be specified for any individual segment. Alternatively, the linear and angular positions, velocities and accelerations for all segments can be printed to the main output file (\*.AOU) at user specified intervals. Since it is necessary to verify that no body segments are subjected to an unexpected acceleration, it is simpler to have the values for all segments printed to the main output file.

Control of the output data is specified in two places in the ATB input deck. Card A.5 contains 36 flags used for program control and output specification. Individual segment position, velocity, and acceleration, as well as individual joint torque time history output may be specified on the H Cards. Since there are so many potential combinations, Ref. [1] should be consulted for a detailed description of the available options. For this example, it is desired to output the tabular time histories of the plane-segment and segment-segment contact forces to individual (\*.T##) output files and the position/velocity/acceleration data for all segments to the main output file. This is done by specifying the appropriate values on the third, fourth and eighteenth flags on Card A.5. The third flag controls the frequency at which the data is written to the main output file. The integer value refers to the number of main program time intervals (discussed in section F below). In this example, the time interval will be specified to be one msec, and the data is to be written to the main output file every 10 msec. The fourth flag determines whether the tabular time histories (plane-segment and segment-segment contacts in this example) are to be printed to individual output files or to a single output file. In this example, individual output files are desired, so the value zero is specified. The eighteenth flag determines what tabular time histories are output. In this case, it is desired to have both plane-segment and segment-segment contacts. Unfortunately, the FORTRAN compiler used to generate the modified (to allow for an increased number of data points in the vehicle excitation) version of the ATB program used for this example does not allow a sufficient number of files to be open simultaneously. Thus, it is necessary to first specify that all plane-segment contact force tabular time histories are desired. Then, in a subsequent run of the ATB program, to specify that all segment-segment contact force tabular time histories are desired. This is done by first specifying a value of five for the eighteenth flag and then by specifying a value of fourteen. See Ref. [1] for a detailed description of what values provide what output files. Figure 63 shows the formatting of Card A.5 for the example.

## **2. Data for Validation Purposes**

Validation of a model is an important step prior to using that model to predict injury levels or gross body motion. In this example, the data available from the experiment includes video footage and triaxial linear accelerometer data for the head, thorax, and pelvis. Thus, the basis of validation of the model of the chair, ATD, and input excitation is the comparison of the predicted and recorded gross body motion and aforementioned accelerations. Output parameter control associated with comparisons to the video footage is discussed in Subsection 3 below. The accelerometers used during the test were located at the centers of gravity of the head, thorax, and pelvis, as shown in Figure 64. For validation purposed, it is desired to compare the three components of acceleration at each of the sensor locations for which recorded data is available. This

type of output is specified on the H Cards in the input deck. Cards H.1, 2, and 3 are used to specify time histories of point linear accelerations, velocities, and displacements, respectively. Cards H.4, 5, and 6 are used to specify time histories of point angular accelerations, velocities, and displacements, respectively. Card H.7 is used to specify time histories of joint parameters.



**Figure 63. Output File Control Formatting.**

As can be seen in Figure 65, tabular time histories of linear accelerations, velocities and displacements for the head, upper torso (thorax), and lower torso (pelvis) are specified. The zero in the second column indicates that the accelerations, velocities, and displacements are all to be output in the local coordinate system. For the three accelerations, the segment numbers (5 = Head, 3 = Upper Torso, 1 = Lower Torso) are given as negative because it is desired that the accelerations be output as if they were recorded by accelerometers located at the specified points. This makes comparison with the recorded acceleration values quite simple. In each case, the coordinates of the point were (0,0,0), thus the values are output for the center of gravity of the segments.

Figure 65 also shows that the angular accelerations, velocities, and displacements for the head are to be output to time history files. While these are not used for comparison with the recorded data, they will be used later for injury estimation. Similarly, the joint parameters for joints 17 and 18, the hinges for the left and right armrests, respectively, are not used for comparison with recorded data, but are used to verify that the joint characteristics were properly defined in the input deck.

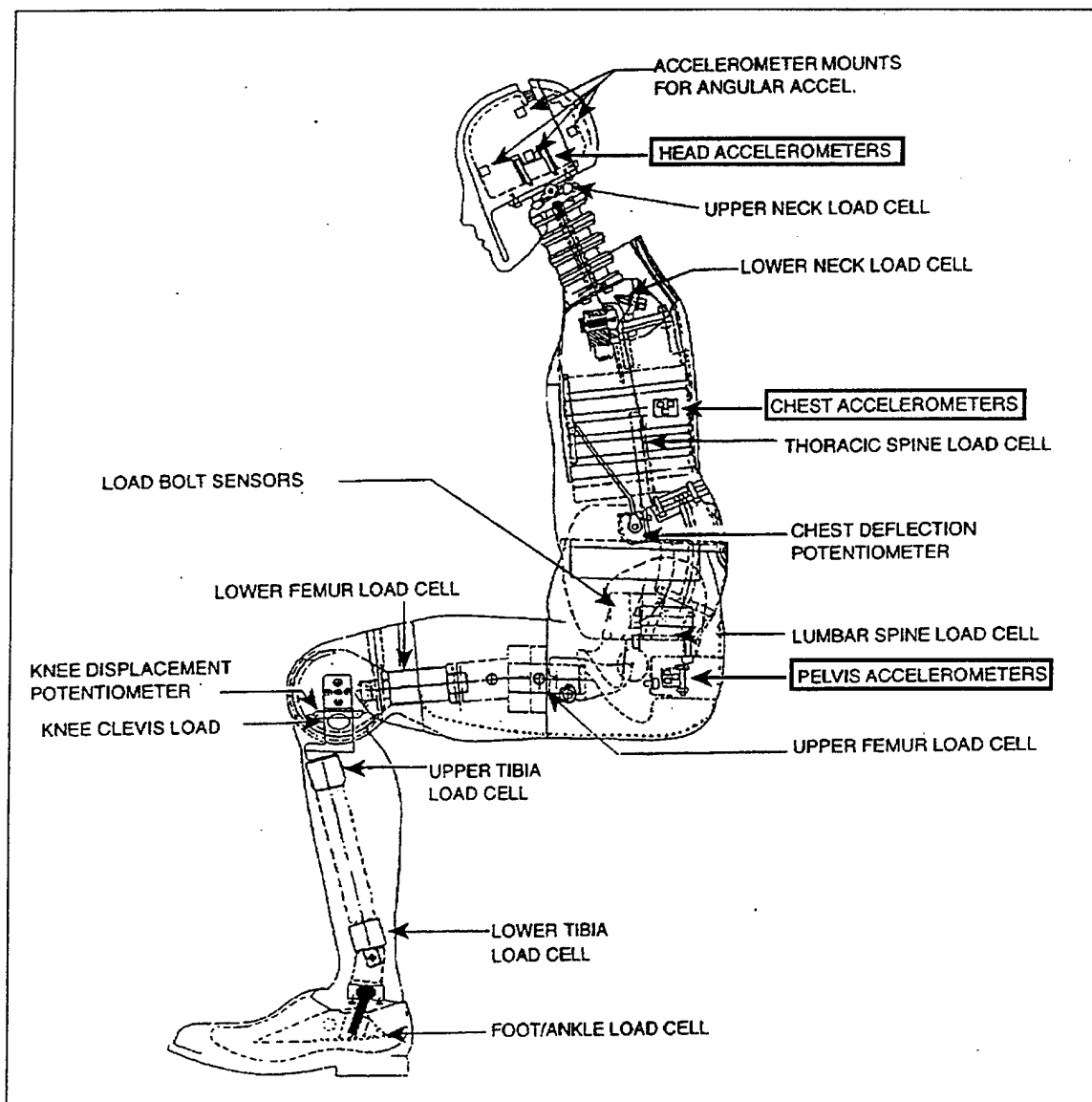
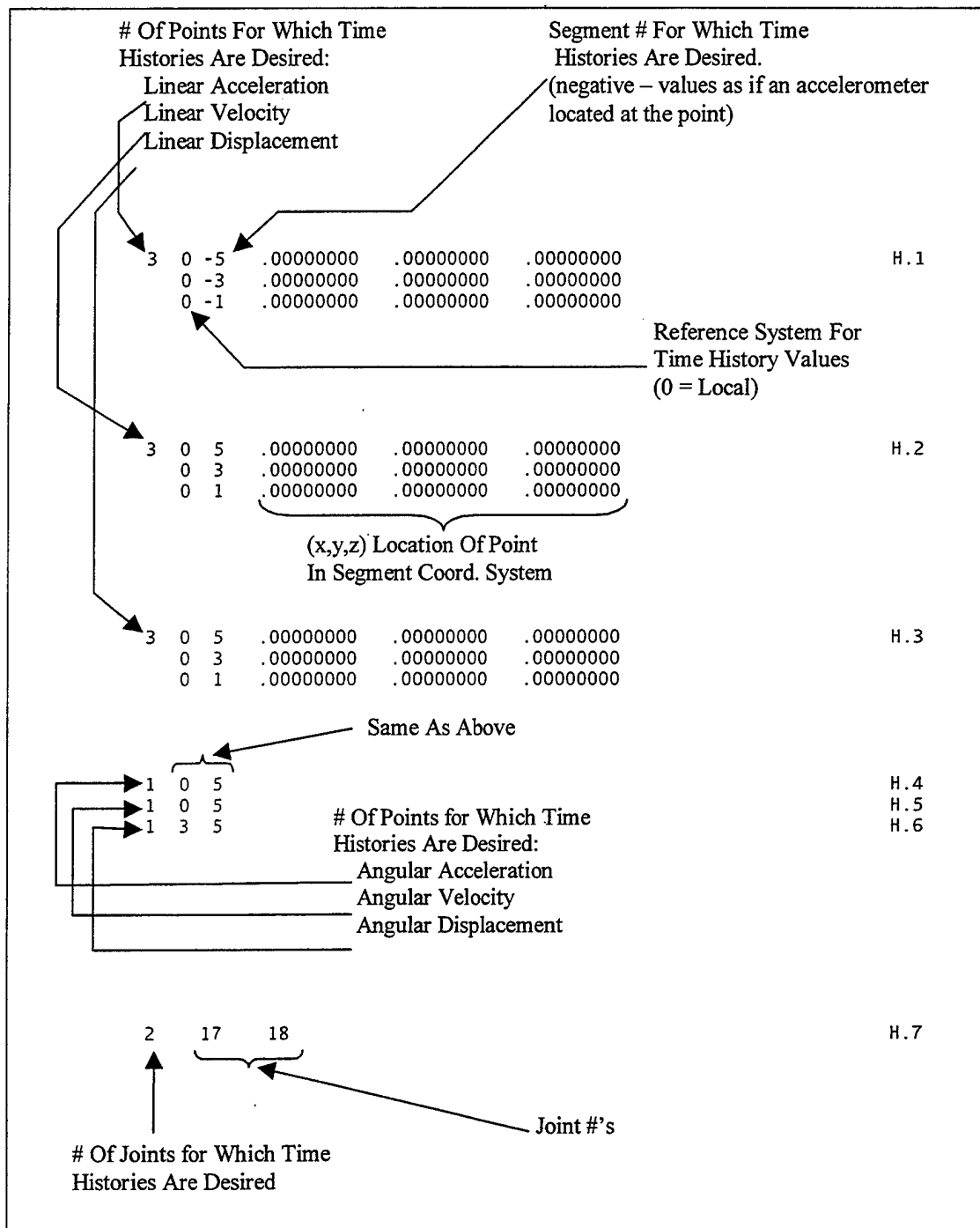


Figure 64. Hybrid III Sensor Locations. After Ref. [6]





**Figure 65. Point Time History Data Formatting.**

### 3. Data for the VIEW and IMAGE Programs

The previous section discussed how to instruct the ATB program to provide the necessary tabular time histories to validate the model against the recorded data. If the data generated during the simulation does not match the recorded data, then something must be changed in the model to represent more accurately the actual test. The problem

is determining what must be changed. Visualization of the gross body motion as predicted by the simulation, and comparison of this motion against the video footage of the actual test, can provide excellent clues as to what problems exist in the model.

As previously mentioned, the VIEW and IMAGE programs can only display images at the times for which data has been generated by the ATB program. They are not capable of interpolating between time steps. In addition, film or video of a test results in a sequence of discrete images rather than a continuous flow. Thus, to make accurate comparisons, the times for which data is provided to the VIEW and/or IMAGE programs must correspond to the times for which recorded images exist. In this example, the motion of the ATD was recorded using a standard video camera. Standard video cameras record images at a rate of 30 frames per second; thus, still images are recorded approximately every 33 milliseconds. Subsequently, it is desired to have the ATB program provide data at 33 msec intervals to the \*.TP1 file for later use in the VIEW and/or IMAGE programs. Referring back to Figure 63, the first flag is seen to be specified as 33, meaning data will be written to the \*.TP1 file every 33 main program time intervals, or every 33 msec.

## **F. PROCESSING PARAMETERS**

The major portions of the input deck have been described in the above sections. In this section, the parameters that specify the unit system, control the length of the simulation, and control the operation of the integration routine are discussed

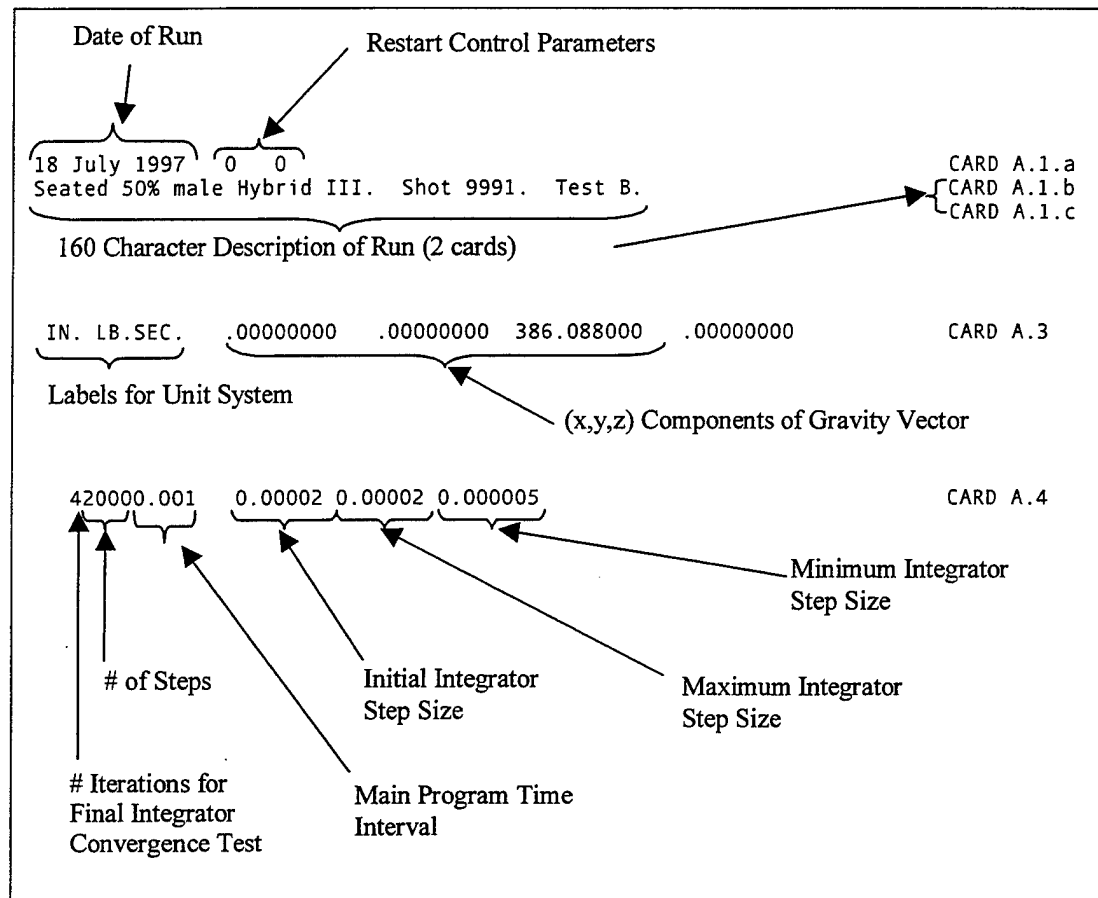
### **1. Primary Control of Time**

The main program portion of the ATB program maintains the primary control of time. A main program time interval is defined by the user, as is the number of steps. Thus, the length of the simulation will be the number of steps multiplied by the main program time interval. At each step, the main program calls the integrator, which processes the simulation for a length of time equal to the main program time interval. At this point, control is passed back to the main program and the appropriate data, as specified in the previous sections, is written to the output files. The values for the number of steps and the main program time interval are specified on Card A.4. The second field is the number to steps and the third field is the time interval. For this example, there are two seconds worth of recorded data. This data is recorded at 0.2 msec intervals, for a total of 10,000 points. To limit the size of the tabular time history files, it was decided that data output every msec would be adequate. Thus, the main program time interval was specified to be one msec and the number of steps to be 2,000 for a simulation length of two seconds. This can be seen in Figure 66.

### **2. Secondary Control of Time**

The integrator routine of the ATB program maintains secondary control of time. The integrator advances time using an integrator time interval that lies between user specified minimum and maximum values. If the integrator cannot achieve convergence using the current integrator time step, then that time step is halved, but is not allowed to be less than the specified minimum. The simulation will terminate if convergence cannot be obtained using the minimum allowed time step. Similarly, the time step is doubled if convergence is satisfied for several consecutive integration steps, but is not allowed to be

more than the specified maximum. Ref. [1] recommends that the main program time interval be an integer multiple of the maximum integrator time interval, and that the maximum integrator time interval be a power of two multiple of both the initial and minimum integrator time intervals.



**Figure 66. ATB Time Control Data Formatting.**

Ref. [1] notes that for most simulations of occupants and pedestrians, suitable main program time intervals are on the order of 10 msec, maximum integrator time intervals are on the order of one to five msec, and minimum integrator time intervals are on the order of one-eighth to one-quarter msec. Obviously, if the input excitation is discretized at 0.2 msec intervals, the above time control values are too large to yield adequate results. As previously mentioned, it was determined that the main program time interval was to be one msec. In this case, the maximum integrator time step was specified to be one-tenth the time interval between input excitation values, or 0.02 msec (0.00002 seconds). The minimum integrator time step was specified to be one-quarter of the maximum, or 0.005 msec (0.000005 seconds). The initial integrator time step was set equal to the maximum integrator time step. The formatting of these values can be seen in Figure 66.

### **3. Miscellaneous Parameters**

The date and a description of the simulation are input on Cards A.1.a, b, and c. Card A.3 contains the labels for the unit system to be used – inches, pounds, and seconds in this example. Card A.3 also contains the specification of the gravity vector. As previously discussed, the definition of the gravity vector partially defines the inertial coordinate system and the convention is to specify this vector as (0,0,g). Thus, the inertial Z-axis points down. The formatting of these parameters can be seen clearly in Figure 66.

### **G. FINAL ASSEMBLY OF THE INPUT DECK**

In the previous sections, the construction of the major components of the ATB program input deck has been discussed. The numbering scheme for the cards makes assembling them relatively simple. However, this report cannot replace the ATB Users Guide [Ref. 1]. When all of the previously generated sections of the input deck have been assembled in the correct order, the user should go line by line through the input deck and verify against Ref. [1] that all required cards and fields have been included and are properly formatted. The complete input deck for this example is included as APPENDIX B.

## IV. RUNNING THE ATB PROGRAM

Once the input deck has been assembled and verified line-by-line against Ref. [1], the ATB program may be executed. This may be performed either in a DOS window or in DOS itself. For initial positioning of the test subject, if it is desired to use the VIEW program for 2-D visualization, then it will be faster to execute the ATB program in DOS rather than in a DOS window. This is because the VIEW program cannot be run from a DOS window, but must be executed from DOS itself.

Execution of the ATB program is performed by typing ATBIV4 at the DOS prompt. The user is then prompted for the name of the input (\*.AIN) file. This filename is entered without the extension. The user is then prompted for the common name for all output files. Each output file will have the same name, but a different extension (\*.TP1, \*.T##, etc.) as previously described. A sample execution of the ATB program is shown in Figure 67. As before, the lighter colored text represents input by the user. Although not shown in the figure, this example was run on a modified version of the ATB program that allows for an increased number of vehicle excitation time points as previously described. This modified version was named Mod1.exe, thus to execute the modified version, type MOD1 at the DOS prompt.

```
D:\Biodyn\ATB Files>atbiv4
ENTER INPUT FILENAME, EXTENSION .ain IS ASSUMED:
$9991
ENTER FILENAME FOR ALL OUTPUT FILES,
EXTENSIONS WILL BE ASSIGNED:
$9991
```

Figure 67. Example ATB Program Execution.

### A. INITIAL TROUBLESHOOTING

A few short runs of the ATB program are typically required in order to locate and correct problems in the input deck and to initially position the test subject. Until these initial problems have been worked out, it is recommended that the length of the run be kept short. It is acceptable to specify the length of the run to be zero time steps.

#### 1. Run-time Errors and Numbered Stops

There are two basic categories of errors associated with execution of the ATB program. The first category of errors is run-time errors, which are those errors that are associated with the FORTRAN language itself. An example of this would be an Invalid Integer Error. This would occur if the ATB program executed a formatted read statement to read in an integer value from the input file, but the corresponding location in the input file contained a real number. The second category of errors is the numbered stops within the ATB program. During the initial reading of the input deck, the ATB program performs some checking of the input data for consistency. If there are inconsistencies, the ATB program terminates execution and returns a numbered stop to the user. The meaning of each of these numbered stops is detailed in Ref. [1]. An example of a

numbered stop is Stop Number 65 which means that the specified number of contact planes exceeds the maximum allowed (30).

Resolution of both the run-time errors and the numbered stops is greatly facilitated by use of the main output (\*.AOU) file. Since the ATB program writes the input information to this file as the input deck is read, the last items written to the output file can be used to indicate the location in the input file that is incorrect. By executing the ATB program, consulting the \*.AOU file and Ref. [1] to correct any errors, and then re-executing the ATB program, any formatting or setup errors can be easily resolved.

## **2. Establishing Equilibrium**

For a simulation to accurately match an actual event, the initial conditions must be the same in the simulation as they were in real life. Typically, this means that the test subject is in static equilibrium. While true static equilibrium is essentially impossible to obtain in the ATB program, a close approximation is possible. Since vehicle excitations are typically applied shortly after the start of the simulation, all that is necessary for equilibrium is for the subject to have no initial velocity and to experience comparably low accelerations.

### **a. Initial positioning of body segments**

The initial positions of the body segments are specified on the G Cards in the ATB input deck. The initial position and linear velocity components are specified, in inertial coordinates, for each reference segment. For a standard body, the reference segment is segment number one, the lower torso. Then, for each subsequent body segment, the user specifies yaw, pitch, and roll angles to define that segment's initial position. The user also specifies what coordinate system these angles are with respect to and the order in which the rotations are to occur.

The process of initial positioning can be confusing since various coordinate systems are used and it can be difficult to visualize the effects of a yaw, pitch, and roll sequence of rotations. Figure 68 shows the formatting of the initial position data for the subject in the example problem. The center of the lower torso is first located by its x, y, and z coordinates in the inertial reference frame as specified on card G.2 as shown in Figure 68. Then the orientation of the lower torso is established by specifying its yaw, pitch, and roll angles with respect to segment number zero (inertial frame). The order in which these rotations occur is given by the 1, 2, 3 sequence near the end of the data card. This sequence – 1,2,3 – indicates that the standard yaw, pitch, roll sequence has been reversed so that the segment is first rolled, then pitched, and finally yawed. Recall that the inertial coordinate system was established such that the X-axis was aligned with the longitudinal axis of the test vehicle, the Y-axis pointed towards starboard, and the Z-axis pointed downward. Thus, with yaw, pitch, and roll angles all set to zero, the test subject would be facing forward in an upright position. Since the proper position for the test subject is seated facing starboard, the lower torso and other segments must be repositioned. As shown on the first G.3.a card in Figure 68, the lower torso is first rolled by three degrees about the inertial X-axis. This corresponds to a three degree lean to starboard. The lower torso is then pitched by 2.5 degrees about the new Y-axis. This corresponds to a 2.5 degree lean backward. Finally, the lower torso is yawed by 90 degrees about the new Z-axis. This corresponds to a 90 degree turn to the right.

Thus, the test subject is now positioned facing starboard with a slight lean backward and to the right.

Each subsequent segment must be positioned in a similar manner. Since the ATB program allows the user to specify in what coordinate system the rotations are to be made, the initial positioning is greatly facilitated. For example, the second G.3.a card specifies zero yaw, pitch, and roll angles for the middle torso with respect to the lower torso. Similarly, each line of the G.3.a cards refers to the positioning of the corresponding body segment.

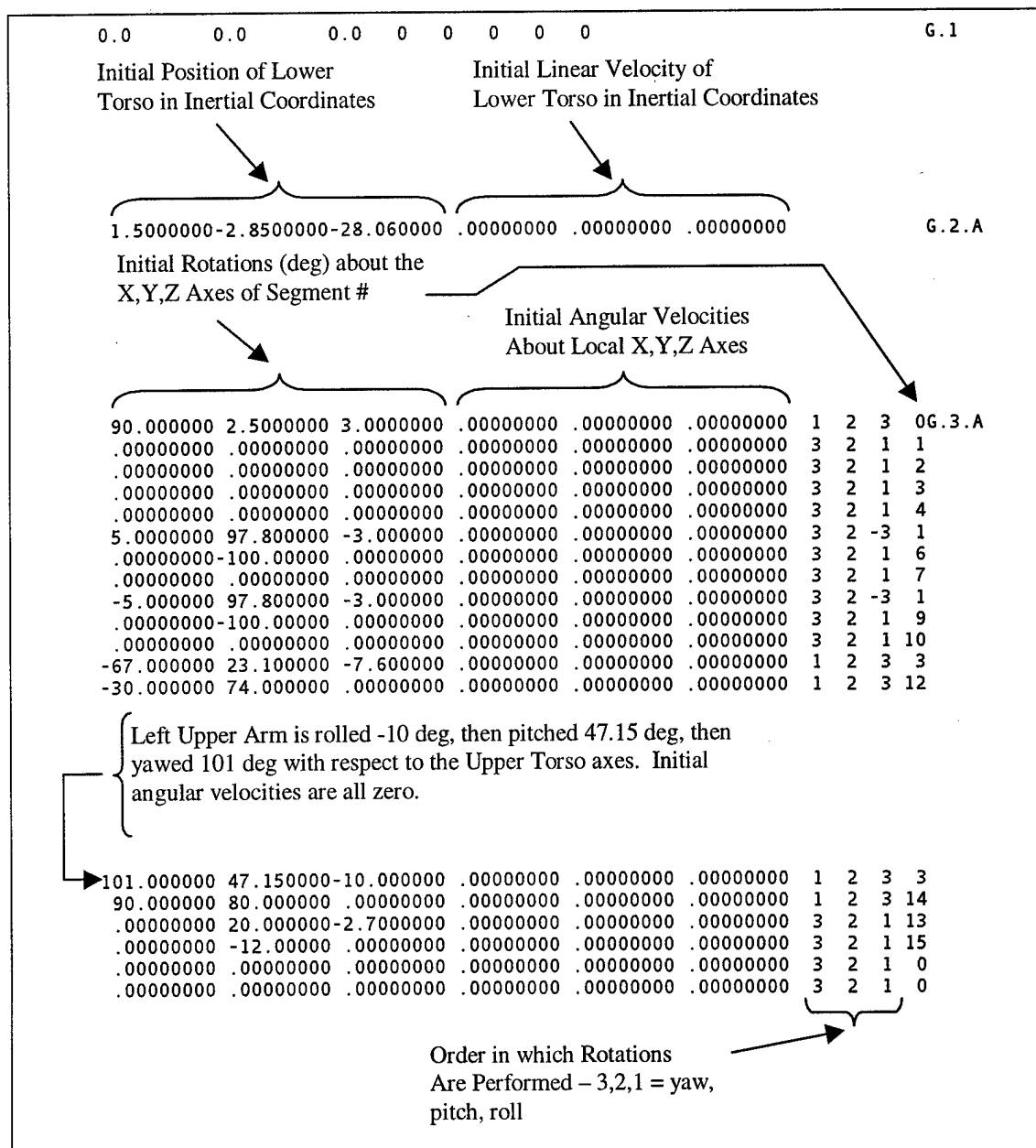
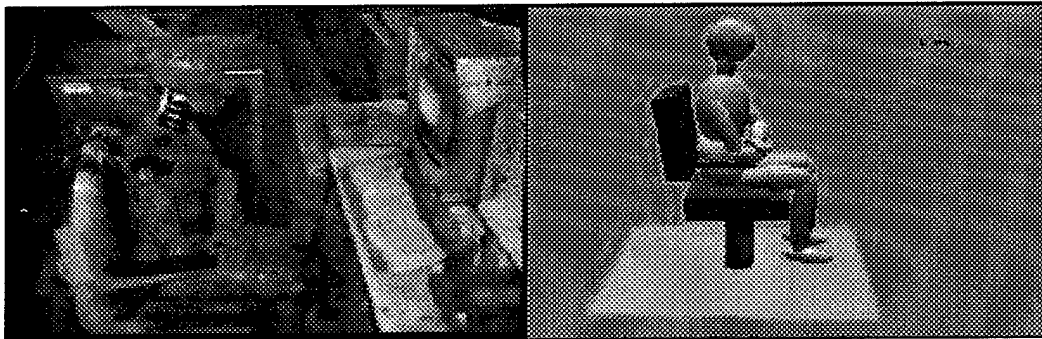


Figure 68. Body Segment Initial Position Data Formatting.

In order to verify that the body segments have been properly positioned, the ATB program can be run and then the resulting positions displayed using either the VIEW or IMAGE programs. In this manner, the test subjects body segments can be positioned such that they match as closely as possible the positions of the test subject in the actual test. Figure 69 shows the initial position of the test subject, as viewed using the IMAGE program, as well as the initial position of the ATD as seen in the videotape of the actual test. By properly orienting the viewing points in the IMAGE program (described in Chapter V), comparisons can easily be made between the initial positioning of the body segments in the simulation and those of the actual subject as seen in the videotape. Recall that the desk was not modeled in this example.



**Figure 69. Initial Positioning of Test Subject.**

#### **b. Verifying equilibrium conditions**

Ensuring that the positions of the body segments closely match those seen in the videotape is only part of the initial positioning process. It is also necessary to ensure that all of the body segments are in equilibrium (as described previously).

Reference [4] provides a suggested procedure for positioning a seated body. This procedure is summarized as follows:

1. Start with torso segments parallel to the seat back and the legs rotated clear of the floor surfaces.
2. Adjust the position of the lower torso to balance more than half of the total body weight.
3. Rotate the upper legs down in order to balance most of the remaining weight of the body.
4. Check horizontal forces.
5. Rotate lower legs to fully balance remaining body weight.

This procedure was used to position the test subject in the example problem. First, the lower torso was positioned such that its contact with the seat bottom balanced most of the weight of the body. That positioning was checked by viewing the file containing the tabular time history of the lower torso to seat bottom contact force after performing a short run of the ATB program. For the example problem, that was file S9991.t28. This file, for a ten msec run, is included as Figure 70. Note that just over 90 pounds is supported by the lower torso. The total weight of the 50<sup>th</sup> percentile male Hybrid III dummy is 168 pounds. Also included in the S9991.t28 file is the right upper leg-seat bottom contact force. This contact supports nearly 37 pounds. Although not shown, the



left upper leg-seat bottom contact also supports nearly 37 pounds. Thus, between the three contacts, the entire weight of the test subject is support. Since the feet of the ATD did not reach the deck in the original test, none of the body weight is support through this contact. Similarly, since there was no contact between the torso of the ATD and the seat back in the original test, none is specified in the initial positioning of the ATB model test subject. Note that after 10 msec, there is no significant change in the distribution of the test subjects weight.

DATE: 18 July 1997		CARD A.1									
RUN DESCRIPTION: Seated 50% male Hybrid III. Shot 9991. Test B.		CARD A.1.c									
PAGE: 28.00											
VEHICLE DECELERATION: Shot 9991 - Sitting 50% Male Hybrid III - SSTV											
CRASH VICTIM: SITTING HYBRID III											
CONTACT FORCES - SEGMENT PANELS VS. SEGMENTS											
TIME (MSEC)	PANEL DEFLECTION (IN.)	1 (Seat) CUSHION FORCE (LB.)	Bottom VS SEG 1 (LT) CONTACT LOCATION (IN.)	ELLIP 1 (IN.)	PANEL DEFLECTION (IN.)	1 (Seat) CUSHION FORCE (LB.)	Bottom VS SEG 6 (RUL) CONTACT LOCATION (IN.)	ELLIP 6 (IN.)			
			X	Z			X	Z			
0.000	1.245	94.33	94.33	1.308	-2.856	-24.500	.614	36.85	36.85	-2.462	5.402
1.000	1.245	94.30	94.30	1.308	-2.856	-24.500	.614	36.84	36.84	-2.462	5.402
2.000	1.245	94.22	94.22	1.309	-2.857	-24.500	.614	36.82	36.82	-2.462	5.403
3.000	1.244	94.11	94.11	1.310	-2.858	-24.500	.613	36.79	36.79	-2.462	5.404
4.000	1.243	93.96	93.96	1.311	-2.859	-24.500	.613	36.76	36.76	-2.462	5.405
5.000	1.242	93.80	93.80	1.312	-2.860	-24.500	.611	36.71	36.71	-2.462	5.406
6.000	1.241	93.61	93.61	1.314	-2.861	-24.500	.611	36.66	36.66	-2.462	5.407
7.000	1.239	93.42	93.42	1.315	-2.862	-24.500	.610	36.61	36.61	-2.462	5.409
8.000	1.237	93.21	93.21	1.317	-2.863	-24.500	.609	36.55	36.55	-2.462	5.410
9.000	1.236	92.99	92.99	1.319	-2.864	-24.500	.608	36.48	36.48	-2.462	5.412
10.000	1.234	92.77	92.77	1.320	-2.867	-24.500	.607	36.41	36.41	-2.462	5.413

Figure 70. Lower Torso to Seat Bottom Contact Forces.

Although the weight of the test subject is properly distributed and the initial positions of the body segments match closely those of the ATD as seen in the videotape of the actual test, the process of establishing initial equilibrium is not yet complete. It is necessary to verify that the positioning of the body segments will not yield significant initial accelerations. These accelerations could be due to contacts between body segments or from torques generated at one or more joints.

In order to verify that no unexpected accelerations are imposed upon any of the body segments, the \*.AOU file may be examined following a short run of the ATB program. Figure 71 shows an excerpt from the S9991.AOU file (included as APPENDIX C). This shows the initial external accelerations of the body segments and the forces and torques on each of the joints. The 386.1 in/sec<sup>2</sup> in the Z direction is the acceleration imposed on all of the body segments by gravity. The additional accelerations imposed on the lower torso and right and left upper legs are due to their contacts with the seat bottom. It can be seen that there are externally applied accelerations present for the right lower arm, right hand, and middle torso. By consulting the appropriate tabular time history files for the segment-segment contacts, it can be established that the right lower arm touches the middle torso and that the right hand contacts the left upper leg. This is in agreement with the initial position of the ATD as seen in the videotape of the original test. Note that there are no unusually large joint forces or torques.

The entire initial positioning and establishing of equilibrium process is highly iterative in nature and can be quite time consuming. A systematic approach, as described above, can make the process significantly easier. Once the user is confident that there are no unexpected contact forces, and that the accelerations experienced by the body segments do not become large (compared to the accelerations to be applied by the vehicle) prior to the application of the vehicle excitation, then the test subject can be

considered to be in initial equilibrium. The process of obtaining a match between the simulation and the actual test may now be started.

SEGMENT		(INERTIAL)			(LOCAL)			KINETIC ENERGY		TOTAL
		U1 ARRAY (IN./SEC.**2)			U2 ARRAY (RAD/SEC.**2)			(LB.-IN.)		
		EXTERNAL LINEAR ACCELERATIONS	EXTERNAL ANGULAR ACCELERATIONS		EXTERNAL LINEAR ACCELERATIONS	EXTERNAL ANGULAR ACCELERATIONS		LINEAR	ANGULAR	
		X	Y	Z	X	Y	Z			
1	LT	-.2025D-15	.3038D-13	-.1276D+04	-.10694D+03	.98991D+02	.39954D+02	.00000D+00	.00000D+00	.00000D+00
2	MT	.8829D+03	-.1463D+04	.1408D+03	-.42639D+03	.61269D+03	.15204D+04	.00000D+00	.00000D+00	.00000D+00
3	UT	.0000D+00	.0000D+00	.3861D+03	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.0000D+00
4	N	.0000D+00	.0000D+00	.3861D+03	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.0000D+00
5	H	.0000D+00	.0000D+00	.3861D+03	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.0000D+00
6	RUL	-.1613D-13	-.2937D-13	-.3258D+03	-.80957D+01	.18905D+02	-.80978D+02	.0000D+00	.0000D+00	.0000D+00
7	NEL	.0000D+00	.0000D+00	.3861D+03	-.43151D-16	.94597D-34	-.14019D-14	.0000D+00	.0000D+00	.0000D+00
8	RE	.0000D+00	.0000D+00	.3861D+03	-.11782D-14	-.44045D-16	-.13238D-14	.0000D+00	.0000D+00	.0000D+00
9	LUL	.2079D+02	.2050D+02	.1814D+03	.32385D+02	.17786D+02	.29110D+03	.0000D+00	.0000D+00	.0000D+00
10	LLL	.0000D+00	.0000D+00	.3861D+03	.10848D-14	.82537D-33	-.34760D-13	.0000D+00	.0000D+00	.0000D+00
11	LF	.0000D+00	.0000D+00	.3861D+03	.29210D-13	-.10921D-14	.32818D-13	.0000D+00	.0000D+00	.0000D+00
12	RUA	.0000D+00	.0000D+00	.3861D+03	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.0000D+00
13	RIA	-.6182D+03	.1025D+04	.5579D+03	-.34128D+02	-.61398D+02	.12577D+02	.0000D+00	.0000D+00	.0000D+00
14	LUA	.0000D+00	.0000D+00	.3861D+03	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.0000D+00
15	LLA	.0000D+00	.0000D+00	.3861D+03	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.0000D+00
16	RHD	-.3220D-03	-.3176D+00	-.1220D+04	-.18943D+03	.63509D+03	.65369D+03	.0000D+00	.0000D+00	.0000D+00
17	LHD	.0000D+00	.0000D+00	.3861D+03	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.0000D+00
18	LAR	.0000D+00	.0000D+00	.3861D+03	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.0000D+00
19	RAR	.0000D+00	.0000D+00	.3861D+03	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.0000D+00
								TOTAL BODY KINETIC ENERGY		
								.0000D+00	.0000D+00	.0000D+00
JOINT	IPIN	(INERTIAL)			(INERTIAL)			RELATIVE ANGULAR		
		JOINT FORCES (LB.)			JOINT TORQUES (IN. LB.)			VELOCITY (RAD/SEC.)		
		X	Y	Z	X	Y	Z			
1	P	0	-.457D+01	.877D+01	-.335D+02	.0000D+00	.0000D+00	.0000D+00	.000	
2	W	0	-.355D+01	.106D+01	-.337D+02	.0000D+00	.0000D+00	.0000D+00	.000	
3	NP	0	-.389D+00	.609D+00	-.586D+01	.0000D+00	.0000D+00	.0000D+00	.000	
4	HP	0	-.160D+00	.193D+00	-.460D+01	.0000D+00	.0000D+00	.0000D+00	.000	
5	RH	0	-.170D+01	.371D+01	-.710D+01	.2899D+02	-.1241D+02	.1227D+00	.000	
6	RA	1	-.152D+00	.104D+01	.583D+01	.5831D+00	.6068D+01	.0000D+00	.000	
7	LA	1	-.155D+00	-.194D+00	-.122D+01	.2263D+01	-.2377D+00	-.2261D+01	.000	
8	LH	0	-.942D+00	.827D+01	-.526D+01	.3243D+02	.5722D+02	-.6581D+01	.000	
9	LA	1	.308D+01	.125D+01	-.648D+00	.4012D+01	.5063D+02	.4389D+01	.000	
10	LA	1	-.380D+01	-.302D+00	.203D+00	.1499D+00	.1869D+01	.1634D+00	.000	
11	RE	0	-.810D+01	-.155D+01	-.561D+01	.0000D+00	.0000D+00	.0000D+00	.000	
12	RES	7	.437D+00	-.410D+01	-.388D+01	-.6331D+01	.1467D+02	-.6184D+01	.000	
13	LS	0	.115D+01	-.165D+01	-.329D+01	.0000D+00	.0000D+00	.0000D+00	.000	
14	BN	3	-.152D+01	.139D+01	.104D+01	.1094D+01	-.5737D+01	.6918D+01	.000	
15	BN	3	-.152D+01	.139D+01	.104D+01	-.1107D+01	.1343D+01	.6917D+01	.000	
16	LW	3	.196D+00	-.241D+00	-.277D+00	.7119D+01	-.5272D+00	.5251D+00	.000	
17	LR	1	.848D+03	-.513D+02	-.559D+00	.0000D+00	-.1135D+04	-.5515D+02	.000	
18	RR	1	.848D+03	-.513D+02	-.559D+00	.0000D+00	-.1135D+04	-.5515D+02	.000	

Figure 71. Initial Accelerations and Joint Forces.

## B. OBTAINING A MATCH

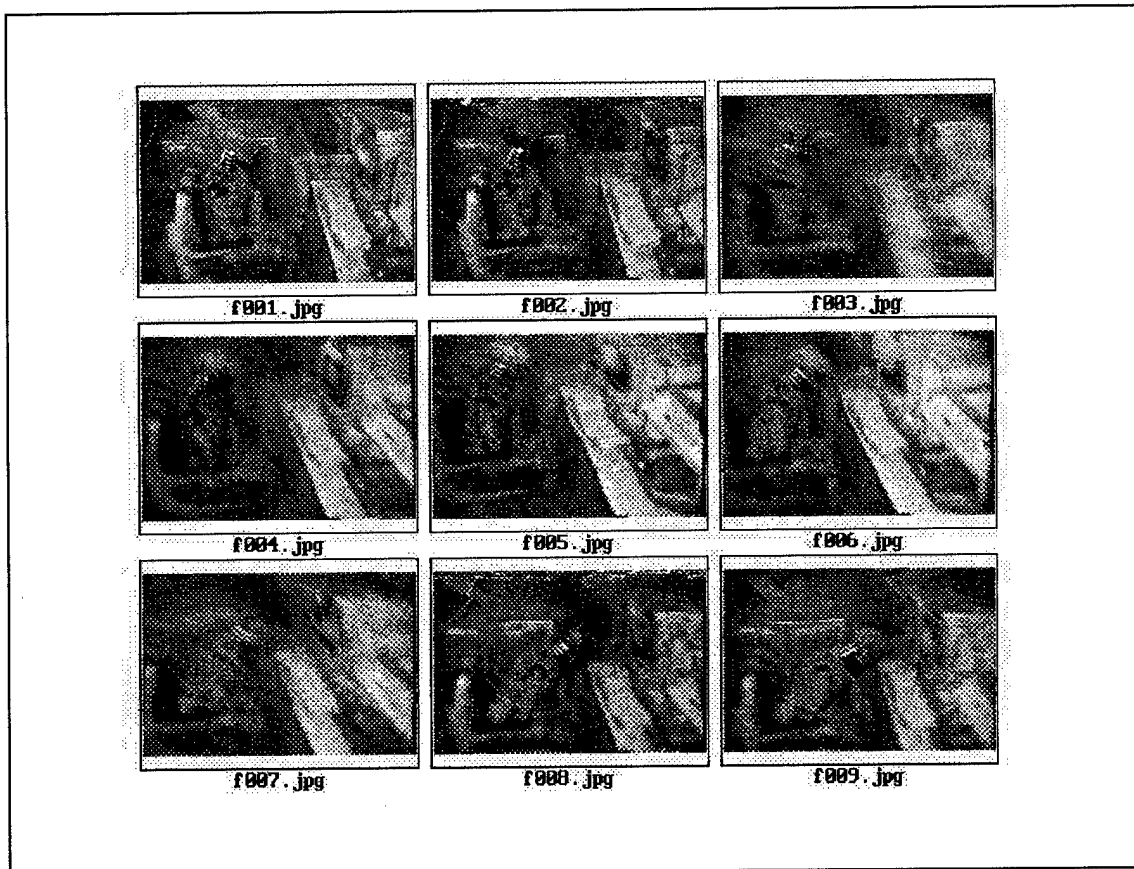
Now that the initial positioning of the test subject within its environment has been accomplished, and the body is in equilibrium, the process of matching the simulation to the test is begun. Matching can be broken down into two categories – visual and numerical. For the example problem, the videotape of the test serves as the visual standard for comparison. Similarly, the measured data from the triaxial linear accelerometers located at the center's of gravity of the head, thorax, and pelvis serve as the numerical standards for comparison.

### 1. Visual Comparison

As previously discussed, the actual test used for this example was videotaped using standard video, resulting in a still frame image of the motion of the test subject being recorded approximately every 33 msec (30 frames per second). These images were captured as individual graphics files using a personal computer equipped with a video capture card. These graphics files were then printed as contact sheets, with nine images per sheet, for use as a visual reference. The first of these sheets is shown (reduced) as Figure 72. Each image represents a 33 msec incremental change in the position of the test subject. Thus, the fourth frame (F004.jpg) corresponds to the position of the test subject at 99 msec  $([4-1]*33=99)$ .

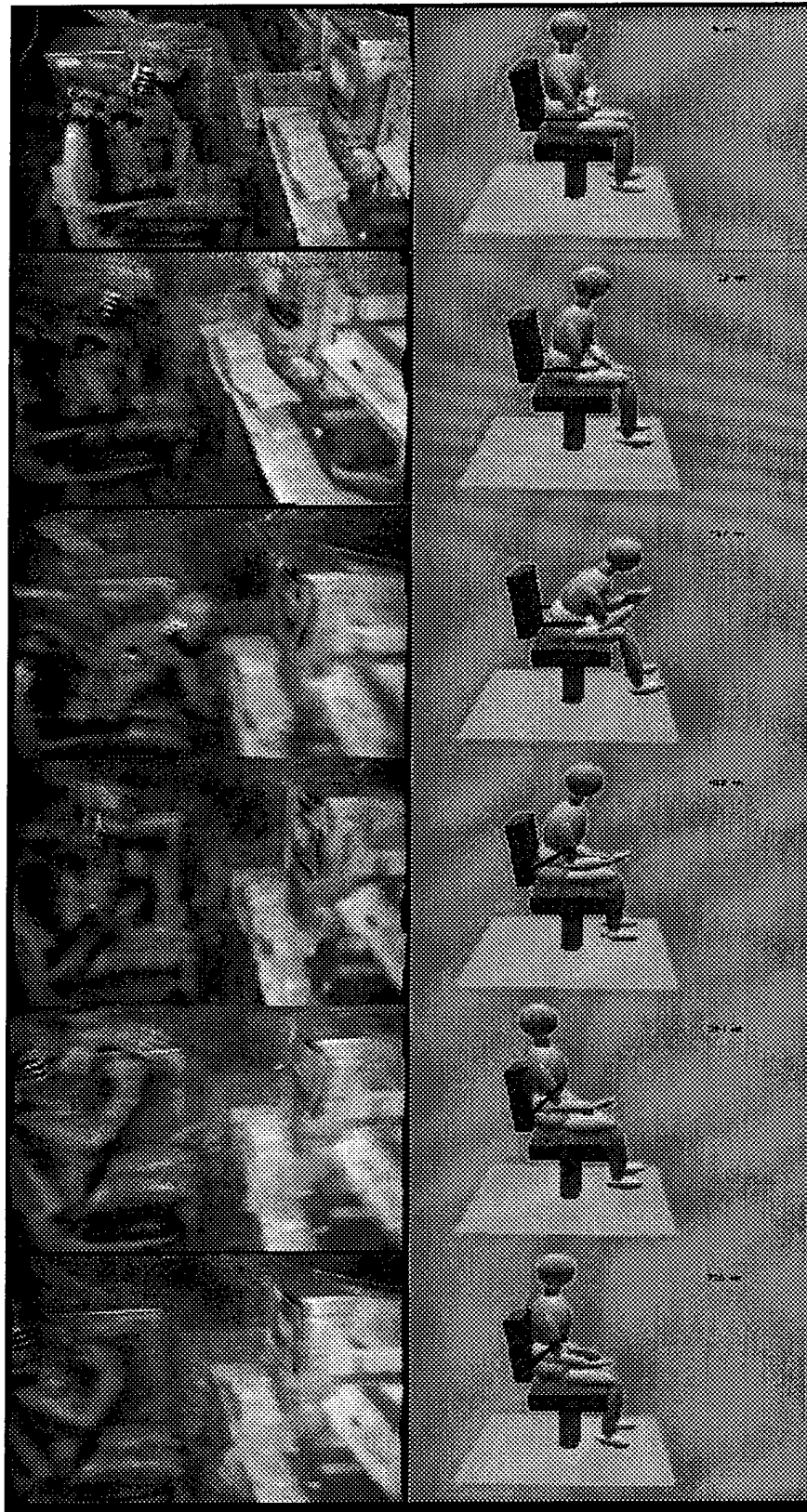
The ATB program is now executed and the resulting predicted motion is compared against the visual reference. Since running the ATB program for the full two second simulation can take significant time (nearly three hours on a 100MHz Pentium PC

for this example), it may be efficient to make shorter runs until the match between simulation and test is close, then perform the full run.



**Figure 72. Example Contact Sheet of Video Capture Images.**

After performing the simulation, visual comparison against the printed contact sheets can be made using the images produced by VIEW or, alternatively, those produced by IMAGE. There are advantages and disadvantages to each. Using VIEW produces 2-D line drawings whereas using IMAGE produces 3-D shaded renderings that are easier to compare against the video images. However, VIEW can be run from the same PC that the ATB program is run from, but to use IMAGE, the \*.TP1 file must be transferred to a Silicon Graphics workstation and the program run there. In either case, the gross bodily motion as predicted by the simulation can be compared to the images captured from the videotape. From this comparison, conclusions can be drawn concerning the accuracy of the simulation. If the match between the simulation and the videotape is poor, then the differences in the motion can often serve as indicators for the problem areas in the simulation. Figure 73 shows several frames of the comparison for the example problem using the IMAGE program. Note that the motion of the torso agrees quite well, but that the motion of the arms is less pronounced in the simulation. This was considered to be of only minor concern. The actual execution of the VIEW and IMAGE programs is discussed in detail in Chapter V.



**Figure 73. Sample Comparison Frames.**

## 2. Numerical Comparison

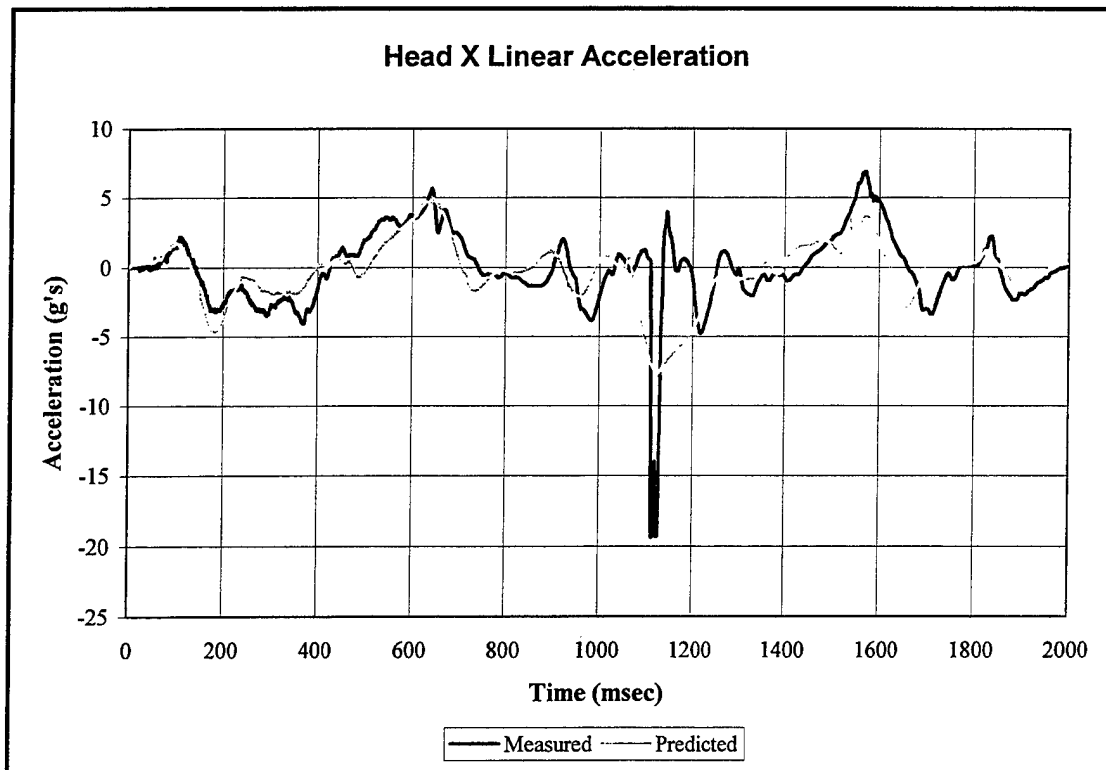
Another significant portion of the validation process is the comparison of predicted to measured accelerations. By specifying the acceleration time histories to be printed out for the head, thorax, and pelvis, as previously described, this comparison process is greatly simplified. The data from the time history files can easily be plotted along with the corresponding measured accelerations using a spreadsheet or data plotting program.

The comparisons between the measured and predicted accelerations for the head X and Z directions are shown in Figure 74 and Figure 75, respectively. The comparisons for the thorax X and Z directions are shown in Figure 76 and Figure 77, respectively, and the comparisons for the pelvis X and Z directions are shown in Figure 78 and Figure 79, respectively. Note that no comparisons were made for accelerations in the Y direction. Recall that the Y direction (for the head, thorax, and pelvis) corresponds to the longitudinal axis of the test vessel. No excitation was specified in this direction, as previously described, and the predominant motion of the test subject occurred in the X-Z (transverse) plane. In addition, the measured accelerations for the pelvis in the Y direction were lost due to a data recorder channel failure. The six figures shown below were all created using Microsoft Excel, but any spreadsheet or plotting program of choice may be used.

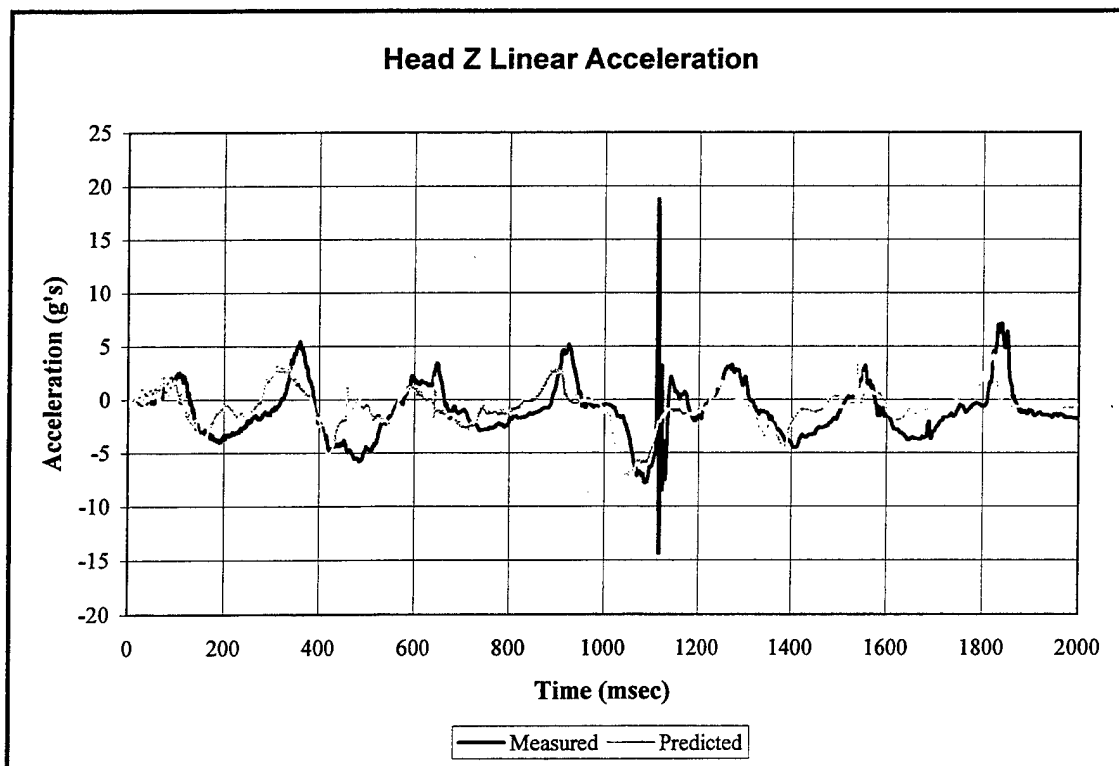
As was the case for the visual comparisons, differences between the measured and predicted numerical results can serve as indicators of problems with the simulation. Using visual and numerical comparisons together, inaccuracies in the simulation may be identified and corrected to yield a better match to the actual test. Some possible problems could include poor initial positioning, poor estimation of plane-segment force-deflection characteristics, and failure to include an important plane-segment or segment-segment contact.

The agreement between the accelerations as predicted by the simulation and those measured during the test, as seen in the following figures, was considered adequate, particularly when viewed in conjunction with the agreement in the visual comparison discussed above. Obtaining an agreement of this quality is a highly iterative process. As described previously, short runs (one second of vehicle excitation) were performed until the first portion of the simulation was in relatively close agreement with the measured data and videotape. Between each of these runs, the visual and numerical comparisons were performed and minor adjustments were made to the input deck. The ATB program was then executed again and the comparison process repeated. Once adequate agreement for the first portion of the simulation was obtained, the runs were extended to full length (two seconds of vehicle excitation) and the process continued.

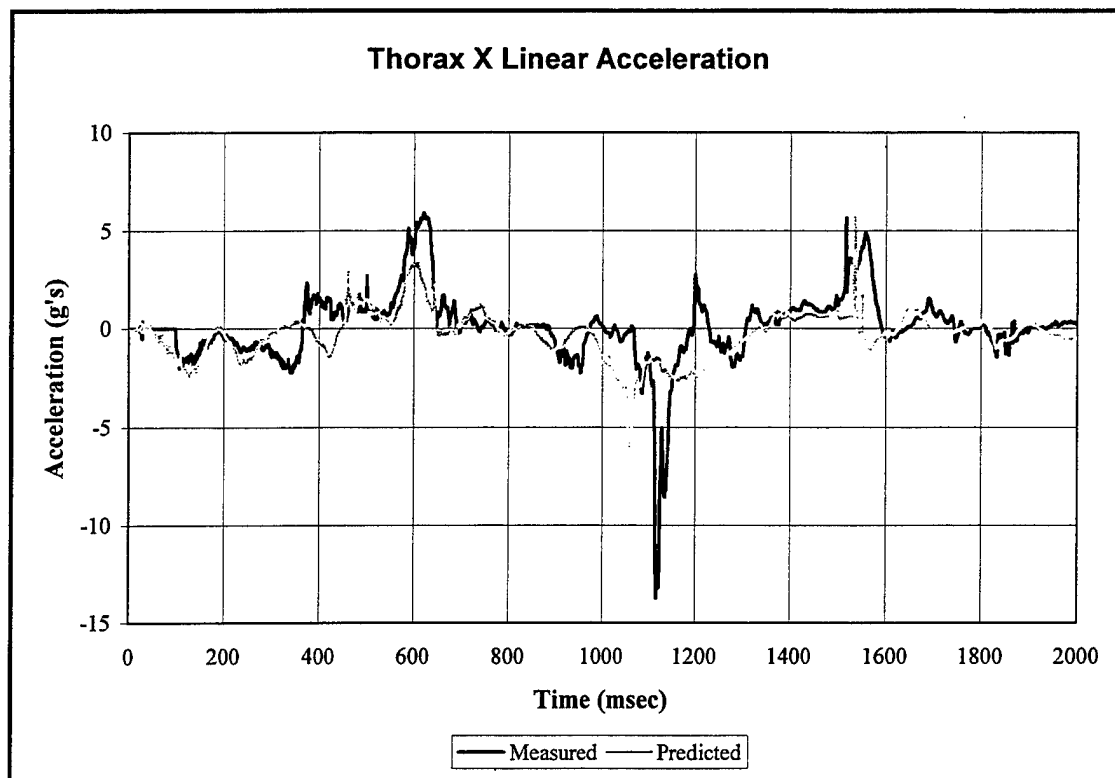
It was found to be beneficial to maintain a record of the major points of disagreement in the visual and numerical comparisons, and of the changes made to the input deck to resolve these disagreements. This helps to identify trends in the quality of the agreement and to determine which modifications should be retained, and which should be discarded. It was also found to be prudent to not change too many parameters at once, for doing so can make it difficult to determine the effects on the output of each individual change to the input deck.



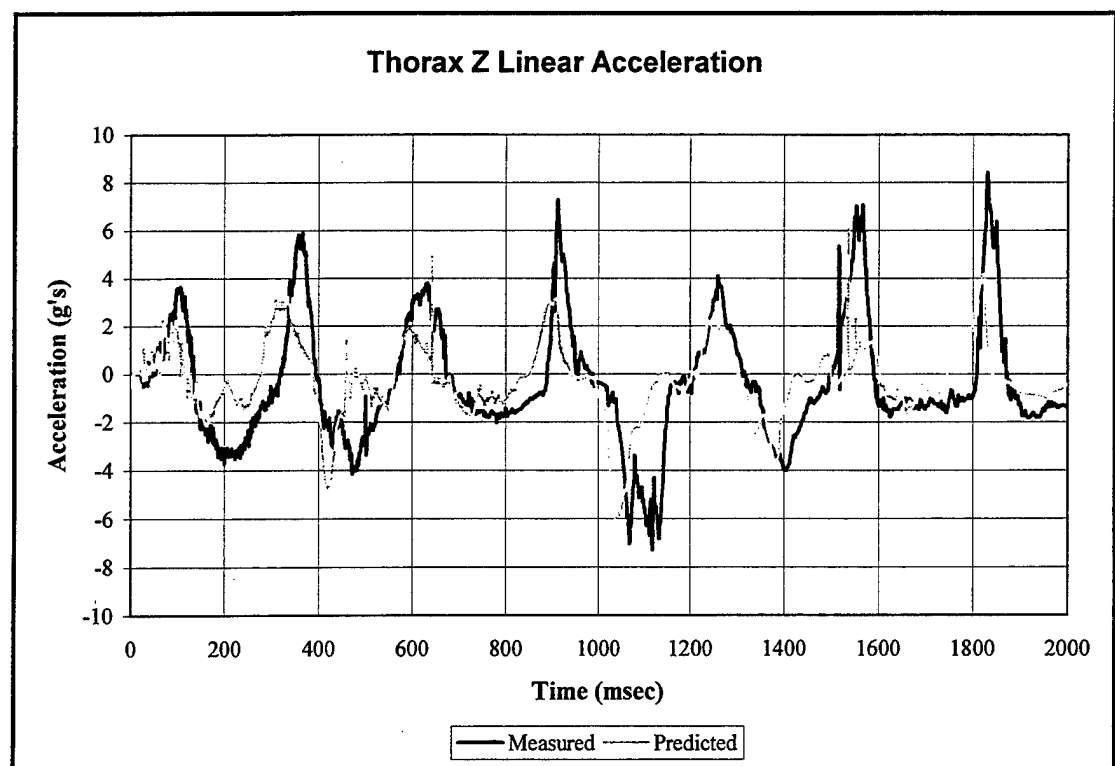
**Figure 74. Comparison of Measured and Predicted Head X Accelerations.**



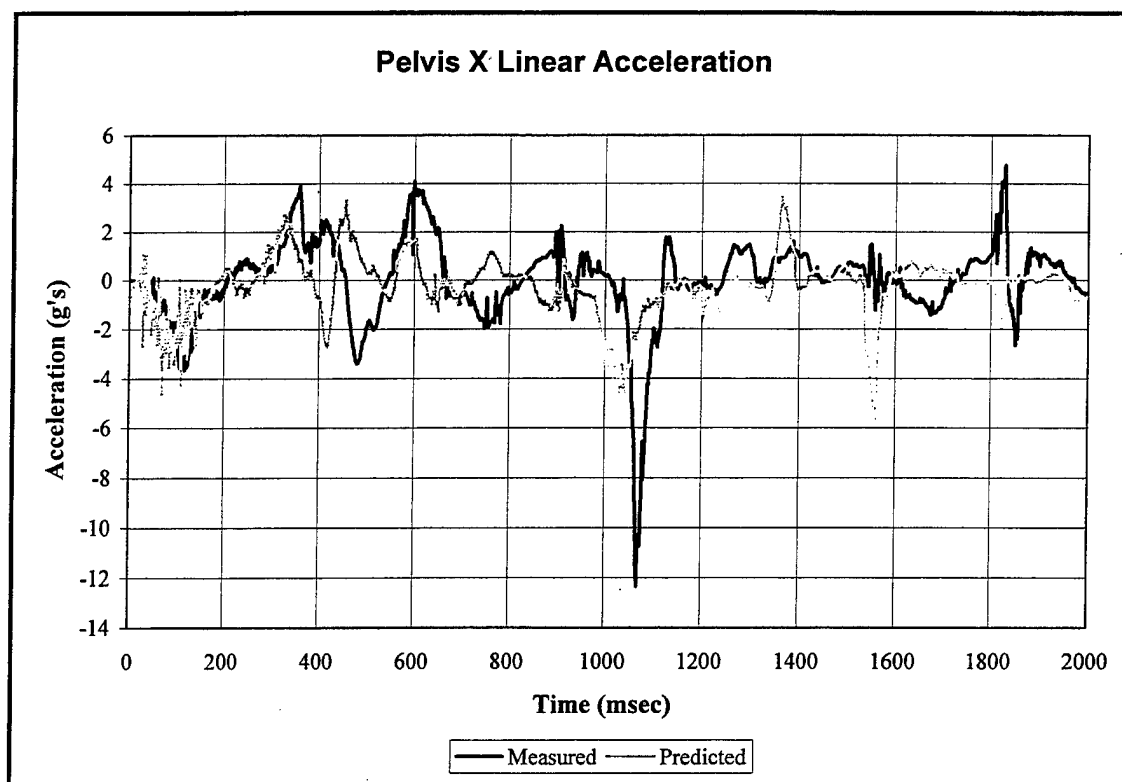
**Figure 75. Comparison of Measured and Predicted Head Z Accelerations.**



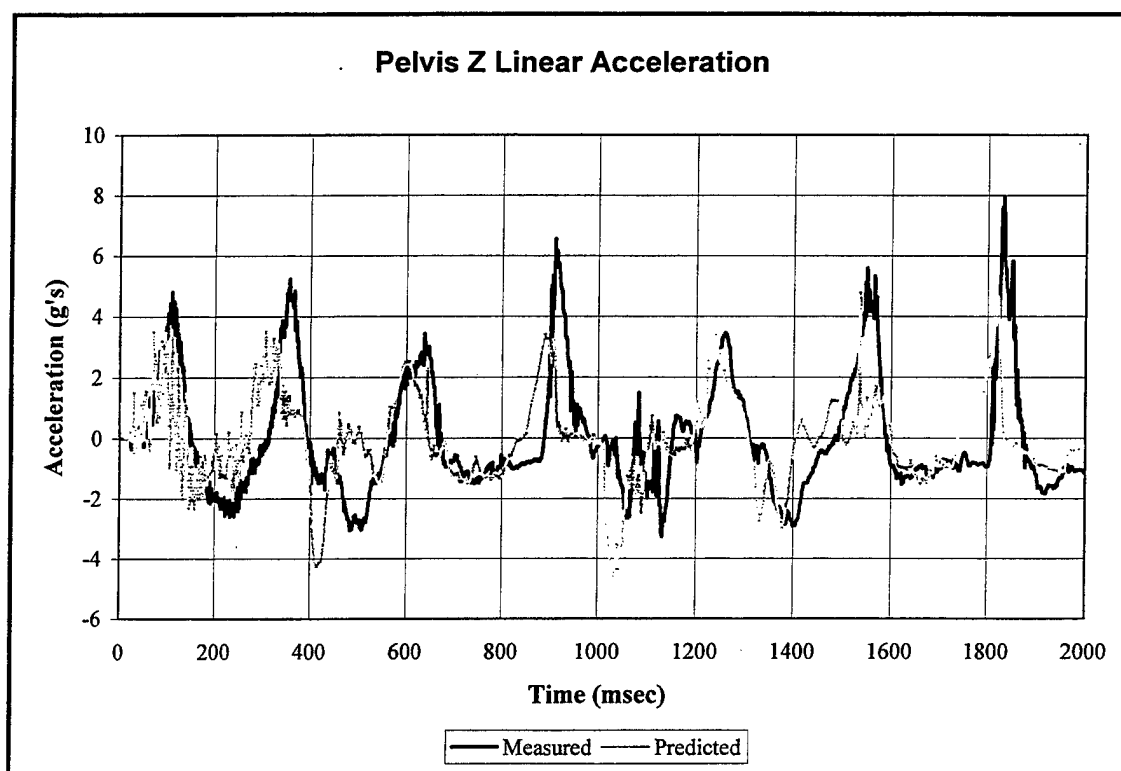
**Figure 76. Comparison of Measured and Predicted Thorax X Accelerations.**



**Figure 77. Comparison of Measured and Predicted Thorax Z Accelerations.**



**Figure 78. Comparison of Measured and Predicted Pelvis X Accelerations.**



**Figure 79. Comparison of Measured and Predicted Pelvis Z Accelerations.**



## C. EXTENSION OF THE MODEL

Once the validity of the model has been ascertained to an acceptable level, the model may be extended as desired. The model of the ATD can be removed and a model of a human being may be substituted. The simulation can then be run and then injury estimates may be compared by comparing predicted accelerations, forces, torques, etc., against corresponding injury tolerances.

### 1. Substitution of Bodies

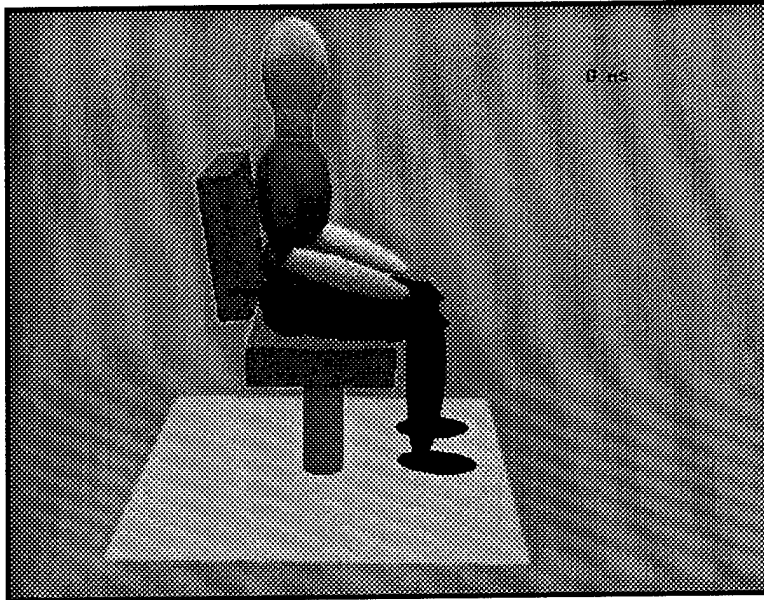
In the previous section, the validity of the model of the chair and the vehicle excitation has been verified to the desired level. Now it is desired to remove the model of the Hybrid III dummy and substitute in models of various humans. In this example, it was desired to substitute in both a 50<sup>th</sup> percentile male and a 5<sup>th</sup> percentile female subject. The GEBOD program was used to generate ATB formatted body data sets for these two human subjects. For each subject, the percentiles (50<sup>th</sup> for the male, 5<sup>th</sup> for the female) were used for both the weight and the height.

The substitution of human subjects for the Hybrid III dummy in the input deck is relatively simple. The portions of the deck relating to the ATD are removed and the appropriate portions from the \*.AIN file generated by GEBOD for the human subjects are inserted in their place. There are some differences in the body data sets for the ATD's and the humans that must be considered when making the substitutions. For the human subjects, GEBOD does not generate the detailed force-deflection functions that were provided in the ATD body data sets. These functions should be removed from the input deck to ensure that they are not inadvertently used for the human subjects. In addition, the dimensions of the body segments for the humans and the ATD will be different, so the appropriate changes must be made in the input deck. For example, the location of the lap belt contact point on the lower torso will be different for the human subjects than it was for the Hybrid III dummy and this change must be made on card D.3.c.

Another major adjustment that must be made to the input deck when changing the test subject is the establishment of equilibrium. Since the dimensions and, in the case of the female, the weight of the test subject have changed, it will be necessary to readjust the initial locations of the segments to reestablish equilibrium. The same process that was used for the ATD may be used for the human subjects.

### 2. Variation of Initial Positions

Another change that can be made as an extension of the model is in the initial position of the test subject. The positioning of the test subject's arms as seen in videotape (see Figure 69) was not considered very realistic. Instead, it was desired to place the arms and hands in a more natural position. Once the model of the 50<sup>th</sup> percentile human male was incorporated into the input deck, the initial positioning of the arms was changed as shown in Figure 80. Again, when any changes are made to the initial positions of the body segments, equilibrium must be reestablished.



**Figure 80. 50<sup>th</sup> Percentile Human Male Initial Position.**

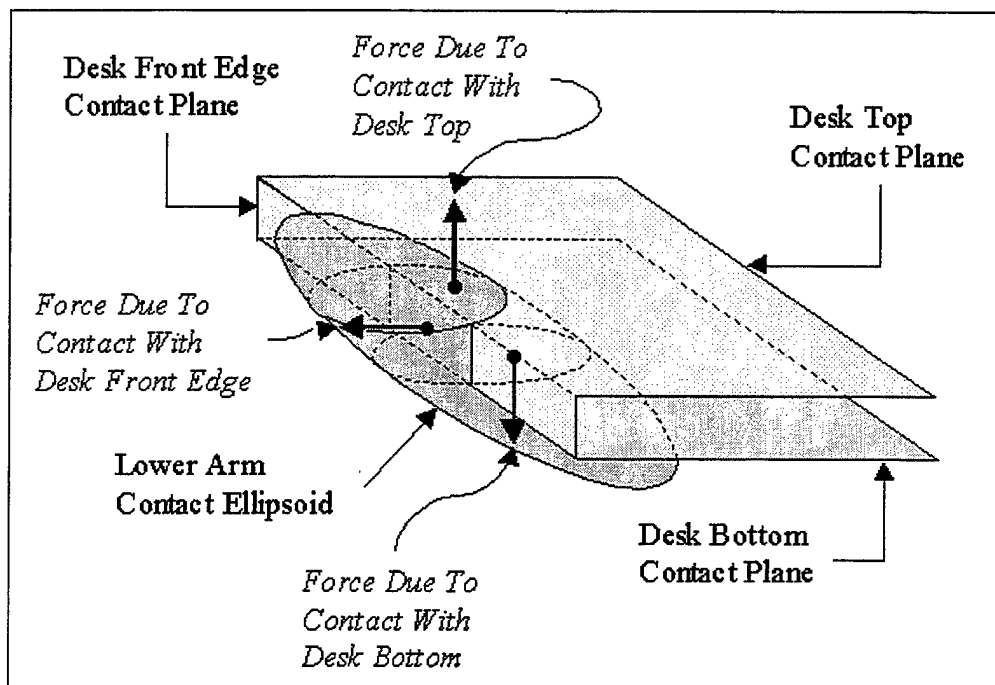
### **3. Additional Changes**

Further changes that were made as extensions of the basic model were removal of the lap belt with the addition of a desk, and addition of a computer terminal and keyboard resting on the desk.

Removal of the lap is very simple. The number of simple belts as specified on card D.1 is changed to zero, and the cards defining the positioning of the lap belt (D.3.a, b, and c), as well as those defining the characteristics of the interaction between the lap belt and the lower torso (cards F.2.a and b), were deleted.

To prevent the test subject from being ejected from the operator's chair entirely and to construct a more realistic environment, a simple desk was added in front of the subject. The desk as seen in the videotape of the original test (see Figure 69) was considered to be too far from the test subject. Thus, the desk added to the model was placed closer to the chair and subject.

A desk can be constructed in essentially two ways. First, a series of contact planes can be defined to represent the top, bottom, and edges of the desk. Second, a single hyperellipsoid can be defined to represent the entire desk. In the development of the model of the desk, the first method was initially attempted and several problems were discovered in the process. For some segments, such as the lower arms, it was considered necessary to allow contacts with the planes representing the top, bottom, and front edge. Since these are finite planes and edge contacts are definitely expected, the edge effect option was specified. Unfortunately, this has an undesired effect for contacts as shown in Figure 81. For a contact between the lower arm segment and the bottom front edge of the desk, one would expect to have components of reaction force normal to both the front edge and the desk bottom. However, since it was necessary to allow contacts between the lower arms and the desk top, a component of force normal to the desk top also arises from this contact. This is a physically unrealistic result and therefore a poor method by which to model the desk.



**Figure 81. Lower Arm to Desk Edge Contact Illustration.**

The second method of modeling the desk, using a hyperellipsoid, was then implemented. The semi-axis lengths of the hyperellipsoid were chosen to be equal to half of the length, width, and thickness of the desk that was constructed from planes. The powers for each semi-axis were specified to be equal and set at a value of 20. Thus, contacts between body segments and the hyperellipsoid representing the desk result in a single force based on the penetration as previously described (see Figure 14). This selection yielded much improved results over the planar contact surface method. A drawback of using a hyperellipsoid is the limitation on the number of segment-segment contacts that may be specified. Recall that this limit is set at 40 by the ATB program and can be easily reached since several body segments must be allowed to contact the desk surface.

#### **4. Changing the Specified Output**

Typically, the purpose of extending a model will include the estimation of injury potentials. In order to make these estimates, the appropriate data must be output by the ATB program. In most instances, this data will be different, or in addition to, the data that was generated in order to validate the model. Thus, the input deck must be altered in order to specify the desired output. The choice of which injury potentials to estimate, and the associated tolerances, will be problem dependant and is beyond the scope of this report.

For the example problem, it was desired to examine, in addition to the linear accelerations of the head, the angular accelerations and velocities of the head. In addition, the relative angular position of the head with respect to the upper torso was desired, as was the torque present at the head-neck pivot point. Finally, the contact forces between the head and the surfaces of the desk and computer were desired. With the

exception of the head-desk and head-computer contact forces, the desired output parameters are all specified using the H cards in the input deck. Most of the output parameter formatting was previously discussed and will not be repeated. Referring back to Figure 65, Card H.6 specifies that the angular position of the head (segment five) is to be output with respect to the coordinate system of the upper torso (segment three). To obtain the head-neck pivot (joint four) torque time history, Card H.7 must contain the number four. For further information concerning the formatting of the input deck for desired output, consult Ref. [1].

## V. USE OF THE IMAGE AND VIEW PROGRAMS

The IMAGE and VIEW programs can serve as invaluable tools for obtaining a match between a simulation and an actual test as well as for visualizing the gross bodily motion of one or more test subjects in an extension of a previously validated model. This chapter covers the setup and execution of each of these programs.

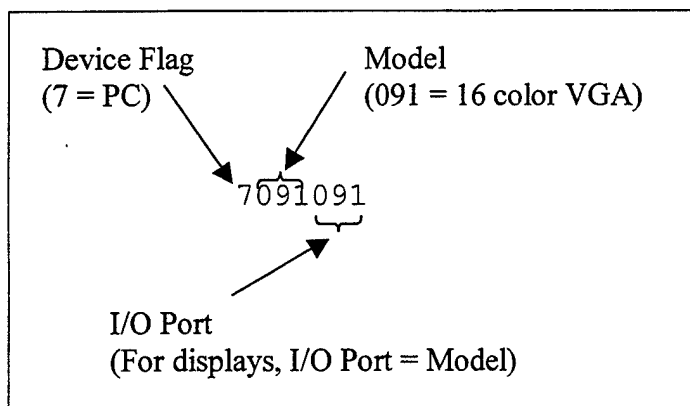
### A. VIEW PROGRAM

As previously described, the VIEW program is run from DOS and produces two dimensional line drawings of the test subject and environment using data provided by the ATB program in the \*.TP1 file. The details concerning the element colors, times, title frames and lines, and viewpoint are specified in the control (\*.VIN) file.

#### 1. Control File

The \*.VIN control file for the VIEW program is constructed in much the way the \*.AIN input deck is constructed for the ATB program, but is significantly smaller. A sample \*.VIN file, as used for the example problem, is included as APPENDIX G. Ref. [3] gives detailed instructions concerning the use of the VIEW program and proper formatting of the \*.VIN file.

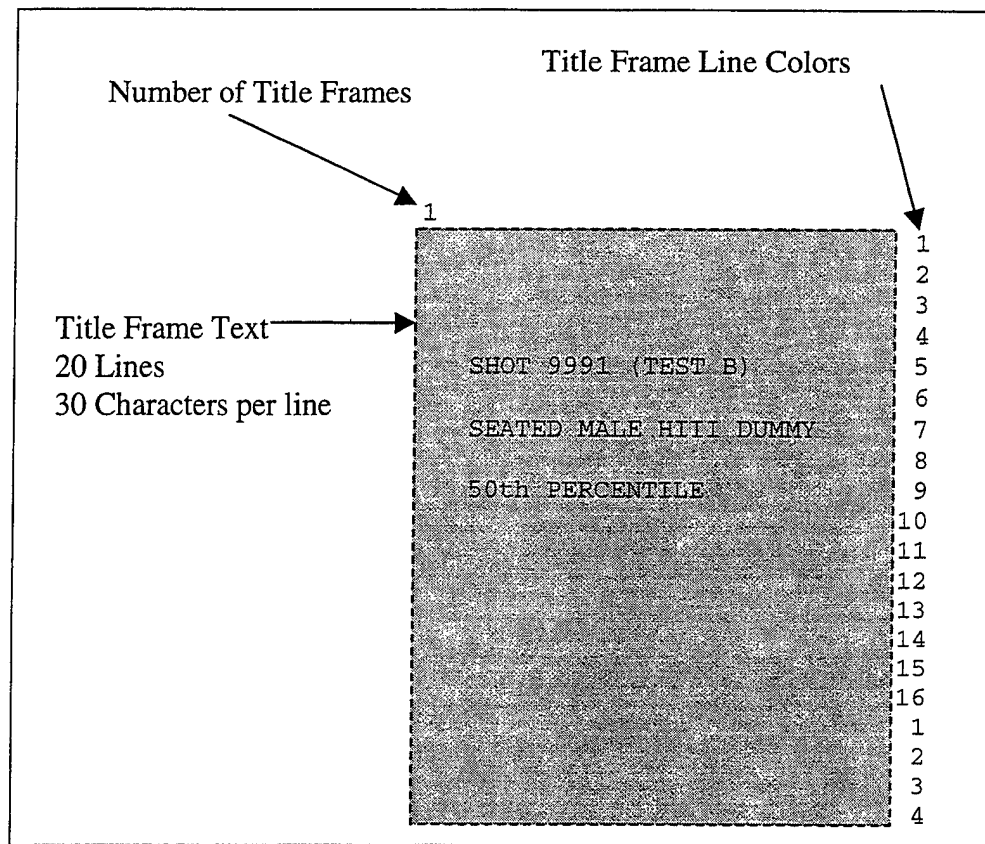
The first line of the control file (each line is referred to as a record, vice card as in the ATB input deck) specifies the output device and format. For use on a PC, the first parameter is set to seven. For output directed to a 16 color VGA (640 x 480) monitor, the next two parameters are set to 091 as shown in Figure 82. Ref. [3] gives an extensive listing of output devices and their associated parameters.



**Figure 82. Output Device Data Formatting.**

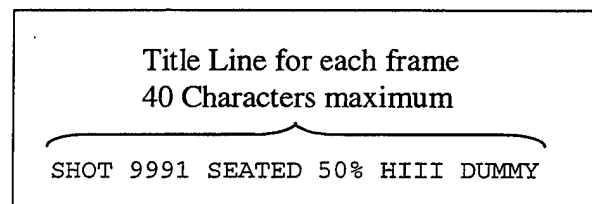
The second line of the control file specifies the number of title frames to be generated. Each title frame consists of 20 lines of text, with up to 30 characters per line. If no title frames are desired, the second line contains a zero and there are no following lines of text. The numbers along the right hand side of the title frame text lines define the color in which the corresponding line of text will be displayed or plotted. The correlation between number and color depends upon the specific device being used for display or

plotting. For each specified title frame, there must be 20 lines of text (blank lines allowed) following. This formatting is illustrated for one title frame, as used in the example problem, in Figure 83.



**Figure 83. Title Frame Formatting.**

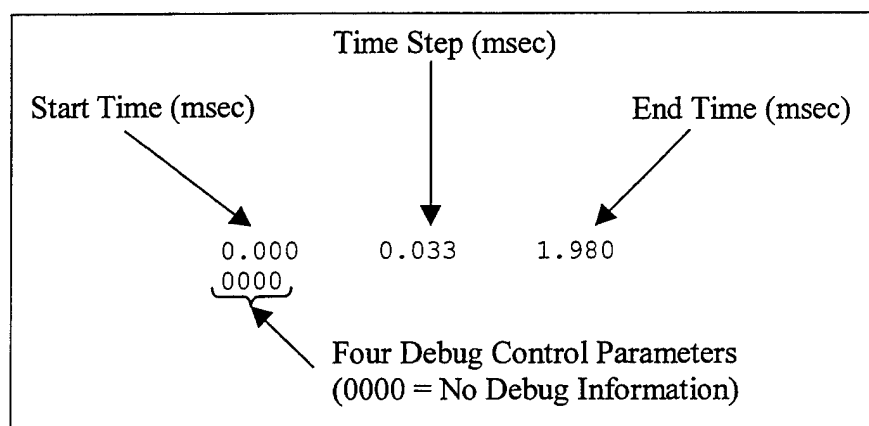
The third record contains the optional one line title that is printed on each frame of the display above the time stamp. If no title is desired, a blank line is inserted into the control file. For the example, the title is as shown in Figure 84.



**Figure 84. Title Line Formatting.**

Records 4.0 and 5.0 contain the time control and debug control parameters, respectively. On record four, the user specifies the start time, end time, and time increment for data plotting. As previously stated, the VIEW program can only plot time frames for which data exists in the \*.TP1file. Thus, the time increment should be an

integer multiple of the time increment used in the ATB program to record data to the \*.TP1 file. For the example problem, in order to match the times for which still images captured from the videotape exist, the time increment was set at 33 msec, the start time at 0 msec, and the end time at 1980 msec as shown in Figure 85. On record 5.0, the user specifies what debug information is desired. For the example problem, no debug information was required, so the four fields were set to zero as shown in Figure 85. For more information concerning what debug options are available, consult Ref. [3].

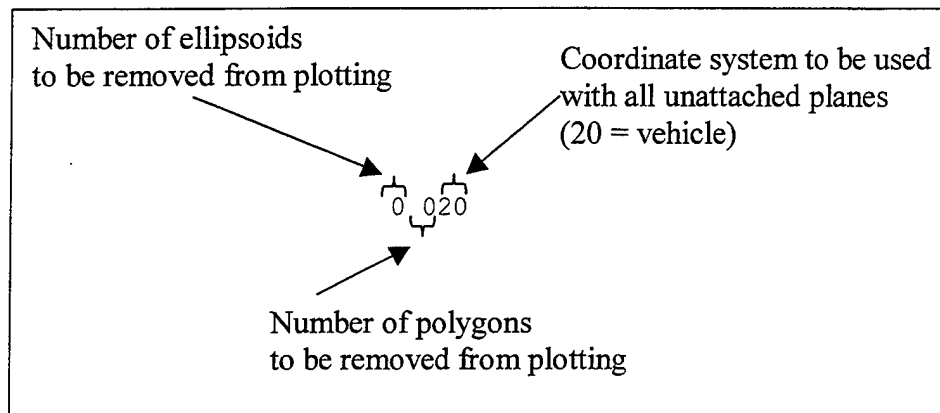


**Figure 85. Time and Debug Control Data Formatting.**

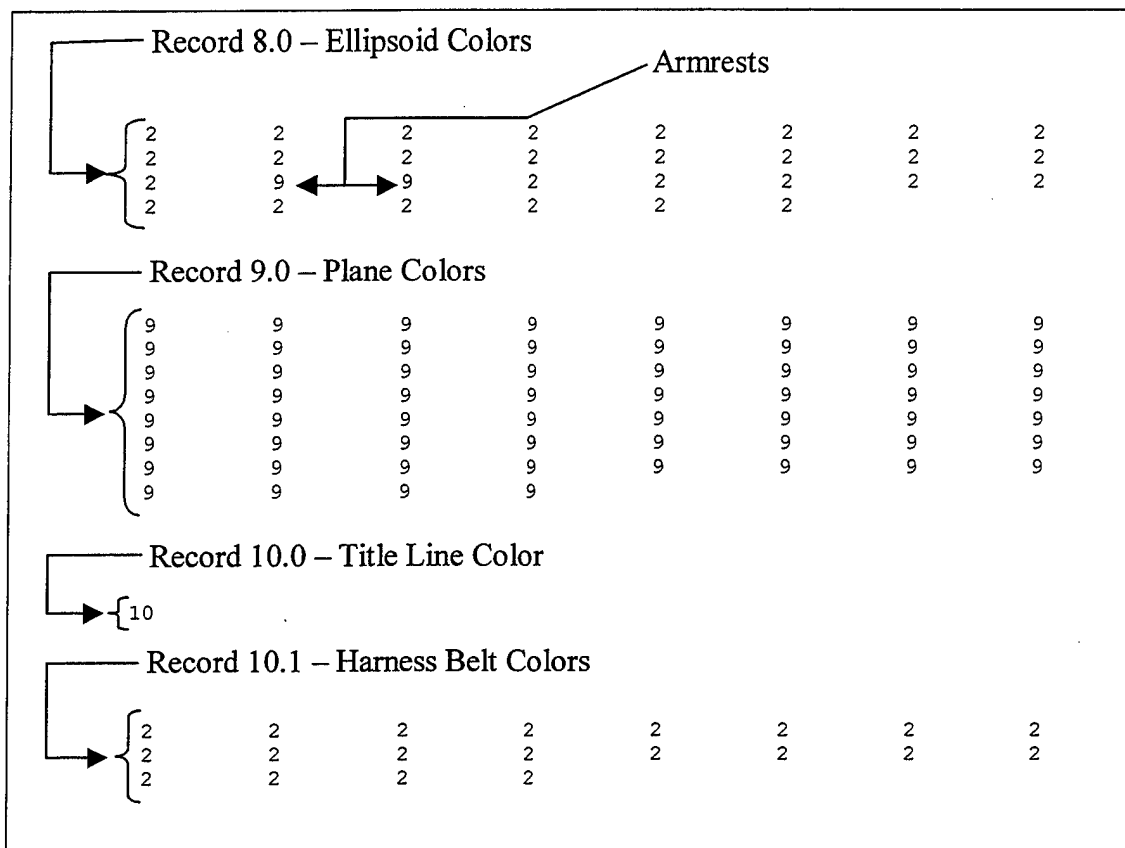
Record 6.0 contains three parameters that control what elements from the \*.TP1 file are plotted. The first parameter specifies how many segments from the ATB program are not to be plotted. Ref. [3] states that plotting extremely small ellipsoids from a great distance should be avoided using the VIEW program and this parameter can be used to eliminate these ellipsoids if they are the last ones defined in the ATB input deck. The second parameter specifies how many polygons (planes) from the ATB simulation are not to be plotted. The specific plane numbers are to be specified on a following line, record 6.1. The third parameter specifies the coordinate system to be used for any unattached planes or planes for which there were no contacts specified on the F cards in the ATB input deck. For the example problem, there were no ellipsoids or polygons to be removed from the plots, and all planes were attached to the vehicle, segment 20. This can be seen in Figure 86.

Record 7.0, 7.1, and 7.2 contain information pertaining to additional polygons that are to be plotted. If no additional polygons are desired, as is the case in the example problem, then record 7.0 contains a zero and records 7.1 and 7.2 are not required. For details on proper data formatting for additional polygons, consult Ref. [3].

Records 8.0, 9.0, 10.0, and 10.1 contain the color information for the ellipsoids, polygons, title line printed on each frame, and harness belts, respectively. As before, the correlation between number and color is device specific. For the example, all body segment ellipsoids were plotted in light green (color #2), all chair components were plotted in blue (color #9), and the title lines on each frame were plotted in green (color #10). There were no harness belts used in the example, so the colors specified on record 10.1 are ignored. This formatting is shown in Figure 87.



**Figure 86. Record 6.0 Data Formatting.**



**Figure 87. Color Specification Data Formatting.**

Records 11.0 and 12.0 contain parameters specifying the manner in which ellipsoids and polygons are plotted. On record 11.0, the user specifies the number of steps used for plotting the contour lines for each of the ellipsoids. On record 12.0, the user specifies the number pieces into which each side of a polygon is divided. If more than 30 polygons are specified, then an optional record 12.1 is included. Record 12.2





175.0) inches. The distance  $D$  is simply calculated as the length of the vector between the two points and its value in the example problem was 868.75 inches. The height of the viewing plane, PPD, was chosen to be the height of the display being used, or 8 inches. Thus, the scale factor can be calculated as  $(8.0/60.0)*868.75$  and the resulting value is 115.8 inches. The width of the viewing plane was also set to the dimensions of the display being used, 11.0 inches. The formatting of the above results on records 13.0 through 16.0 can be seen in Figure 90.

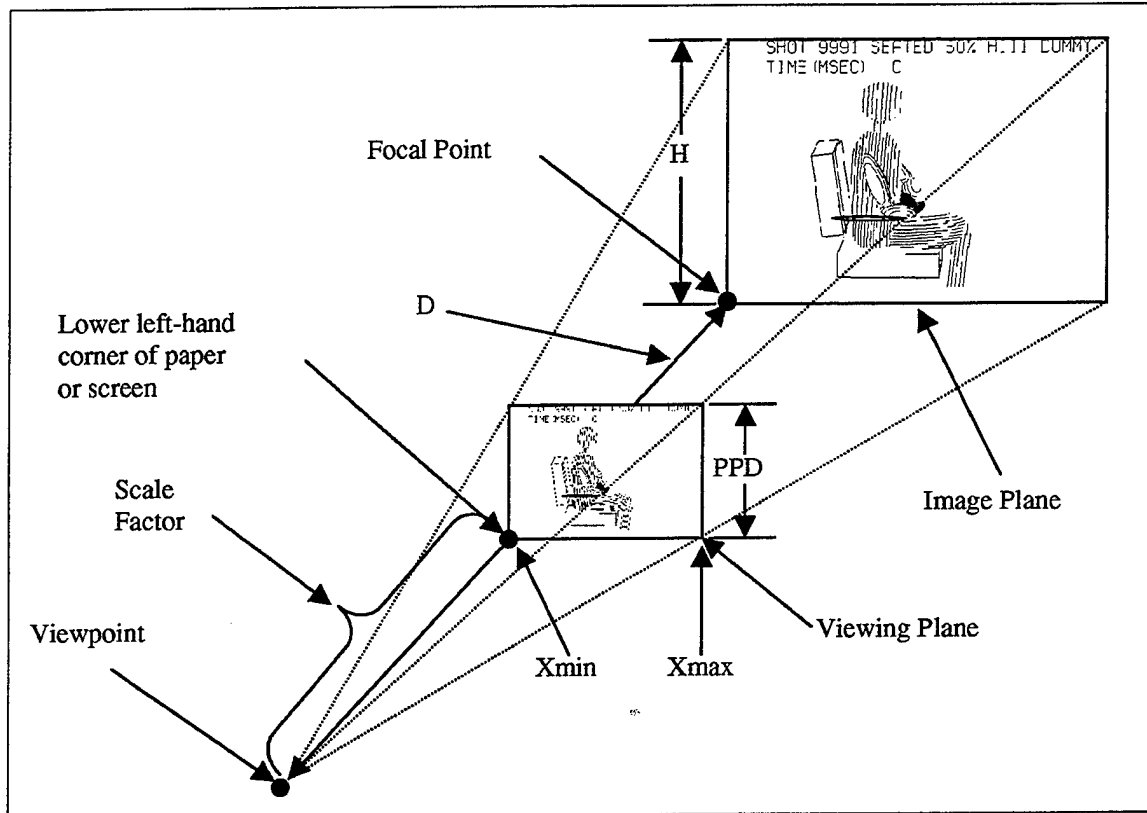
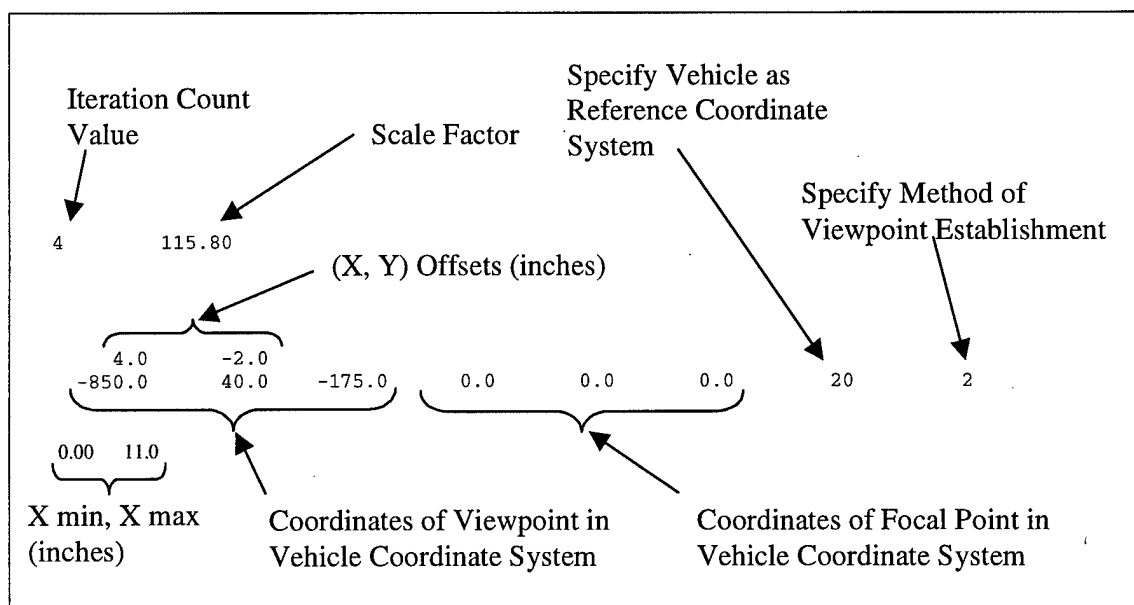


Figure 89. Viewpoint Illustration. After Ref. [3]

## 2. Printing VIEW Images

The printing of the images generated by VIEW is highly device dependent. As previously stated, Ref. [3] contains a listing of devices and ports which may be used in conjunction with the VIEW program. Only two of these options will be mentioned here. First, if it is desired to print only a single image, that image can be saved as an encapsulated postscript file for later printing on a postscript capable printer. This option can be exercised by specifying the model to be 111 and the port to be 011 for deferred plotting. Second, an entire series of frames can be saved to a file in the Hewlett Packard Graphics Language (HPGL) for latter viewing or printing using a program capable of reading HPGL files. This may be performed by specifying the model to be 030 and the port to be 010 for deferred plotting.



**Figure 90. Viewpoint System Data Formatting.**

## B. IMAGE PROGRAM

As previously described, the IMAGE program is run from a Silicon Graphics (SGI) workstation and produces three dimensional shaded renderings of the test subject and environment using data provided by the ATB program in the \*.TP1 file. The details concerning the element colors, additional planes, and viewing orientation are specified in the setup (\*.SETUP) file.

### 1. Execution of IMAGE

The image program is executed from UNIX by typing "image filename", where filename corresponds to the name of the \*.TP1 file, but does not include the extension. The program then searches for a file with the same root name, but with a .setup extension. For more information concerning the execution of the IMAGE program, consult the user's manual included as APPENDIX A.

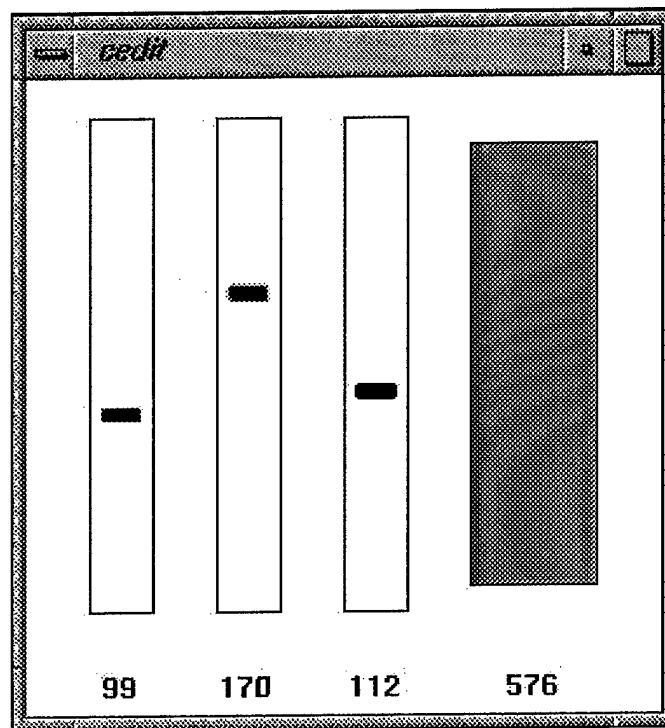
### 2. Setup File

The \*.setup file required by the IMAGE program is similar in nature to the \*.VIN file required by the VIEW program. In the \*.setup file, the colors for the ellipsoids and planes are specified, additional planes may be defined, and a viewpoint system similar to the one used in the VIEW program is defined. However, the IMAGE program does not render harness belts, does not provide for title frames or title lines (although a time stamp is displayed), and does not allow the user to specify which frames from the \*.TP1 file are to be displayed.

The general construction of the \*.setup file is less rigorous than that of the \*.VIN file. IMAGE is C based, whereas VIEW is FORTRAN based. Specifications in the \*.setup file are performed using keywords and pairs of keywords. These keywords can have mixed cases, but must be spelled exactly as defined in the user's manual, including

the underscore and equal sign followed by a space. In addition, single line comments may be included in the \*.setup file by preceding the comment text by “/\*” and following the text by “\*/”. In addition, the order in which the parameters are specified is generally not significant. The user’s manual (APPENDIX A) gives further details concerning the ordering in keyword pairs.

As for the VIEW program, each individual plane or ellipsoid must have a specified color. With the IMAGE program, these colors are defined using red-green-blue (rgb) triplets. The value of each color component is an integer between 0 and 255. The triplet (0,0,0) corresponds to black, and (255,255,255) corresponds to white. A convenient way to determine what triplet values corresponds to what colors is to execute the command “cedit” which brings up a window with three slider bars, one for each component, and a color window that displays the resulting color. Figure 91 shows the CEDIT window and an example color definition.

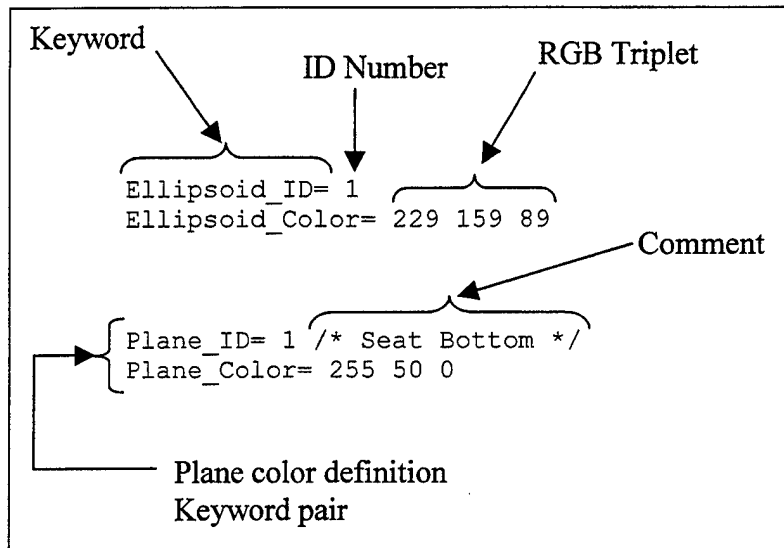


**Figure 91. CEDIT Window.**

Once a color has been determined using the CEDIT utility, the specification is performed in the \*.setup file. This is done through use of pairs of keywords for both planes and ellipsoids as shown in Figure 92. The two keywords (ID Number and Color) may appear in any order, but the usage must be consistent.

Additional planes may be defined in the IMAGE program much like additional polygons could be defined in the VIEW program. This is done using the Add\_Plane keyword and the specification of the (x,y,z) coordinates of the four corners of the plane. In the example problem, several planes were added to represent the physical surfaces of the chair that were not modeled in the ATB program. Additionally, If there were any

planes defined in the ATB program that did not have any allowed contacts, they will not be rendered by the IMAGE program. Thus, to have these planes rendered, they must be added in the \*.setup file. Figure 93 shows the format for the addition of the back of the seat bottom. This plane was not originally defined in the ATB program, but rendering is desired for aesthetic purposes. A comment line is included to identify what the plane represents, followed by a line containing the (x,y,z) coordinates of the four corners defining the plane. These values are referenced to the coordinate system of the segment to which the plane is attached. This attachment occurs in the following pair of keywords in which the plane ID is assigned and the plane is attached to segment number 20, the vehicle in the example problem. Finally, the color specification pair of keywords follows.



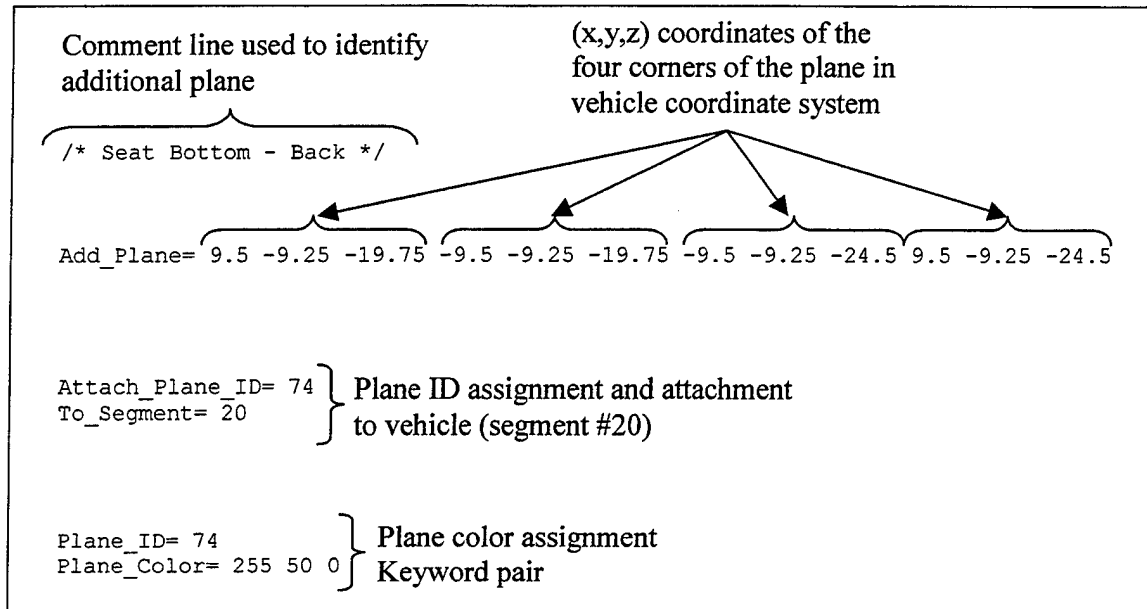
**Figure 92. Color Specification Data Formatting.**

Although it was not necessary for the example problem, planes and/or ellipsoids can be removed from the plotting just as was the case with the VIEW program. This removal is simply done for planes by using the keyword "Remove\_Plane\_ID= ", followed by the plane ID number as specified in the ATB program. Similarly, ellipsoids may be removed by using the keyword "Remove\_Ellipsoid\_ID= ", followed by the ellipsoid ID number as specified in the ATB program.

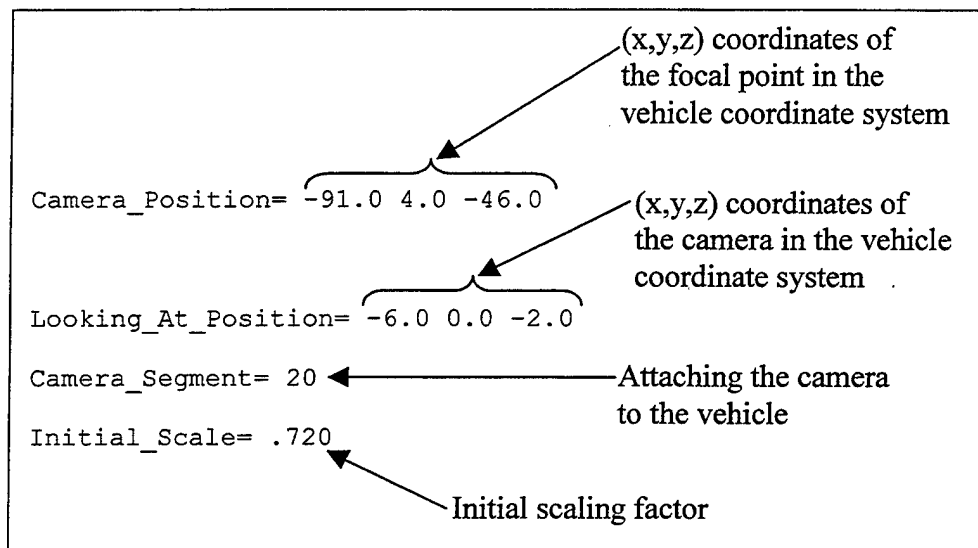
The IMAGE program does not allow for the generation of title frames or title lines, but does provide a time stamp on the rendering. The user has control over both the color of the background and the color of the time stamp. This is accomplished using RGB triplets, as described above, and the keywords "Background\_Color=" and "Time\_Color=".

A viewpoint system similar to the one used in the VIEW program is defined by the user in the \*.setup file. A camera position (corresponding to the viewpoint) and a looking at position (corresponding to the focal point) are defined in the coordinates of the segment to which the camera is attached (also a user specified quantity). An initial scale, similar to the scale factor in the VIEW program, is defined to control the size of the

image in the window. The user also has the option to specify initial yaw and roll angles. In the example problem, the camera was attached to the vehicle, segment number 20, and the camera position, looking at position, and initial scale were specified as shown in Figure 94.



**Figure 93. Additional Plane Data Formatting.**



**Figure 94. Viewpoint Data Formatting for IMAGE.**

### 3. Interactive Functions

The IMAGE program provides a simple, easy to use, interactive interface. When the program is executed, the IMAGE window appears as shown in Figure 95. In the right upper corner are several buttons that control the play of the simulation. Below these

buttons is a region containing information regarding the simulation. By pressing any of the control buttons (left-click with the mouse), the simulation may be easily controlled. During play of the simulation, the perspective can be changed by using the mouse positioned anywhere in the viewing window. Holding down the left button and moving the mouse results in zooming (increasing or decreasing the scale factor of) the image. Holding down the middle button and moving the mouse results in rotation of the image. Finally, holding down the right button and moving the mouse results in translation of the image. Since the values for the camera position, looking at position, scale factor, yaw and roll angles are all displayed along the right side of the window, the mouse may be used to position the image in a desired perspective, then the appropriate values recorded. These values can then be used in the \*.setup file to reproduce the same perspective upon initial execution of the IMAGE program.

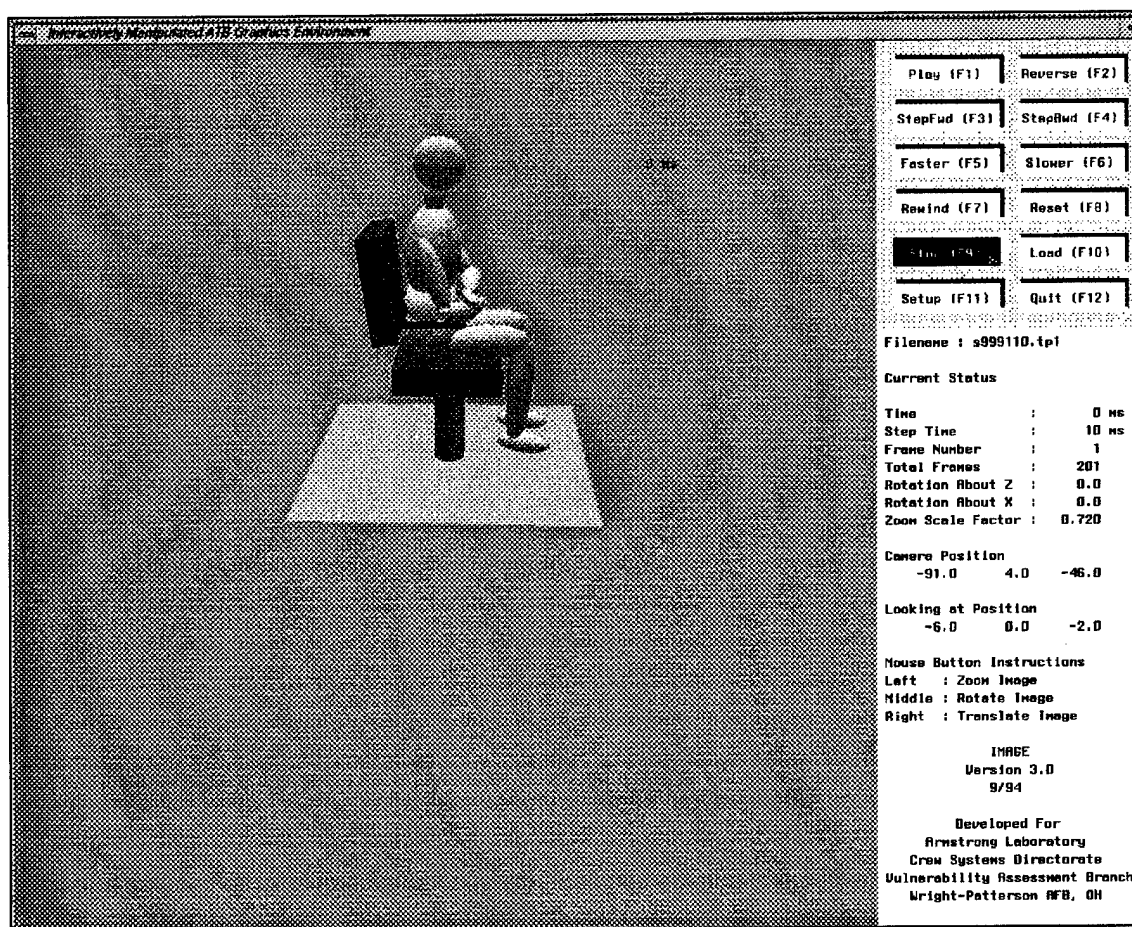


Figure 95. IMAGE Interactive Window.

#### 4. Video and Still Images

The three-dimensional renderings produced by the IMAGE program are ideally suited for producing still frame or video images. The manner in which these images may be recorded is dependent upon the specific hardware and software installation being used, but one method will be discussed here. The Media Recorder program can be used either

to capture still frame images or to create a movie file. If still frame images are created, they may later be combined to produce a movie file. These images or movie files can then be compared against videotape of an original test for the purpose of validation, or can be used for easy visualization of gross bodily motion.



## VI. SUMMARY

The ATB program, and the associated GEBOD, VIEW, and IMAGE programs, provide a powerful simulation and modeling group capable of examining the biodynamic response of humans or anthropomorphic test devices subjected to vehicle excitations caused by underwater explosions. Models can be validated against measured quantities, such as accelerometer data and videotape from actual test events. These validated models can then be extended in order to develop estimated injury potentials or to visualize gross body motion. Graphical representation of the body motion as predicted by the ATB program can be accomplished using either the VIEW program, for two-dimensional line drawings, or the IMAGE program, for three-dimensional shaded renderings. These graphical representations can then be displayed on a screen, printed to paper, or recorded to image or movie files for later use. For further details concerning the use of these programs, consult References [1], [2], [3], and APPENDIX A.

## APPENDIX A. IMAGE VERSION 3.0 USERS MANUAL

IMAGE v. 3.0

USERS MANUAL

9/94

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COMMAND LINE:

☐

To start the program just type:

image [Data File Root Name [Resolution]]

where brackets indicate options. Resolution is in degrees.

If the program is started without a data file name, the user is prompted for a data file name. Whether the name is typed on the command line or at the prompt, the file must be an ATB '.tpl' file. Enter only the root name; the extension '.tpl' is added by the program.

The program will also look for a setup file with the same root name and the extension '.setup'. If the program is unable to open that file, it will try to open a setup file named "default.setup". If the program is unable to open either of these files, then the current values or internal default values will be used. For a list of setup values that can be set, see the section on the SETUP FILE. If suitable data and setup files are provided, then the program will display the first frame of that file in the modeling screen.

### RESOLUTION:

If a resolution is provided as an integer on the command line, then that value will be used to specify the polygon size in the ellipsoid generation. Smaller resolutions give better looking images, but cause the program to run slower. Unpredictable results will occur if the resolution provided does not divide evenly into 180 degrees. It is also recommended that the resolution not be greater than 60 degrees. Default resolution is 30 degrees; 15 degrees produces nicely smoothed ellipsoids suitable for permanent recording.

Note that the resolution can only be set in the command line, after the file root name. It cannot be entered when the filename is entered after prompting, or when the interactive "Load" button is used.

### SETUP FILE:

The program allows the user to have some control over the graphical environment by accessing a setup file. The program determines the parameters to be set by the use of keywords. The keywords can be in mixed case, but each must be spelled exactly as given, including underscores (\_) and equal sign. Be sure to leave a space after the equal sign; the keyword and equal sign are read by the program as a data constant. Note also that the setup file follows 'c' language conventions so that comments may be added if preceded by '/' and closed by '/' (must be on a single line).

The list of currently supported keywords and their meanings follow. Note for RGB colors, to see what color the RGB triplet corresponds to, use the GL library command 'cedit'.

Background\_Color= 0 125 255

Sets the background color for the modeling screen. The color is specified as an integer red, green, and blue triplet, where the values range from 0 to 255. The default color is black (0 0 0).

Time\_Color= 0 0 0

Sets the color for the time stamp text. The color is specified as a red, green, and blue color triplet, values 0 to 255. Default is yellow (255 255 0).

Ellipsoid\_Color= 25 200 100

Will set the color of the ellipsoid specified by Ellipsoid\_ID to the red, green, blue color triplet specified, where the values range from 0 to 255. May be set before or after setting the Ellipsoid\_ID, providing you are consistent. The Ellipsoid\_ID and its color are taken as pairs in the order they are read in. The color applies only to the matching Ellipsoid\_ID read in. After a pair is read in, the color is set and internal flags are reset. The default is blue (150 150 255).

Ellipsoid\_ID= 3

Identifies the ellipsoid to be colored with Ellipsoid\_Color. May be set before or after setting the Ellipsoid\_Color, providing you are consistent. The Ellipsoid\_ID and its color are taken as pairs in the order they are read in. The Ellipsoid\_ID applies only to the matching Ellipsoid\_Color read in. After a pair is read in, the color is set and internal flags are reset.

Plane\_Color= 200 200 200

Will set the color of the ellipsoid specified by Plane\_ID to the red, green, blue color triplet specified, where the values range from 0 to 255. May be set before or after setting the Plane\_ID, providing you are consistent. The Plane\_ID and its color are taken as pairs in the order they are read in. The color applies only to the matching Plane\_ID read in. After a pair is read in, the color is set

and internal flags are reset. The default is light grey  
(200 200 200).

Plane\_ID= 3

Identifies the plane to be colored with Plane\_Color.  
May be set before or after setting the Plane\_Color,  
providing you are consistent. The Plane\_ID and its color  
are taken as pairs in the order they are read in. The  
Plane\_ID applies only to the matching Plane\_Color read in.  
After a pair is read in, the color is set and internal flags  
are reset.

Remove\_Ellipsoid\_ID= 10

Removes the specified ellipsoid from the modeling object list.

□

Remove\_Plane\_ID= 10

□

Removes the specified plane from the modeling object list.

□

□

Add\_Plane= 0.0 0.0 0.0 10.0 0.0 0.0 8.0 9.0 0.0 1.0 7.0 0.0

Adds a plane with the vertices specified. Each group of  
three values is assumed to be the x,y, and z coordinates  
of a vertex. The points are read in and used in the order  
specified. The points are assumed to be planar, this means  
the points are not tested to determine if they are planar.  
The normal to the plane is calculated using the cross product  
of the two vectors Point 2 - Point 1 and Point 3 - Point 1. The  
plane identification number starts with 71.

Attach\_Plane\_ID= 71

Identifies the plane to be attached to segment To\_Segment.  
May be set before or after setting the To\_Segment, providing  
you are consistent. The Attach\_Plane\_ID and its To\_Segment  
are taken as pairs in the order they are read in. The  
Attach\_Plane\_ID applies only to the matching To\_Segment read in.  
After a pair is read in, the attachment is made and internal flags  
are reset.

To\_Segment= 1

Identifies the segment to attach Attach\_Plane\_ID to.  
May be set before or after setting the Attach\_Plane\_ID, providing  
you are consistent. The Attach\_Plane\_ID and its To\_Segment  
are taken as pairs in the order they are read in. The  
Attach\_Plane\_ID applies only to the matching To\_Segment read in.  
After a pair is read in, the attachment is made and internal flags  
are reset.

Camera\_Position= 25.0 85.0 -20.0

The position, in ATB data file units, of the camera. The  
default is (25.0, 85.0, -25.0). Use 'Initial\_Scale'  
to change size.

Looking\_At\_Position= 25.0 0.0 -20.0

The position, in ATB data file units, for the camera to look at. The default is (25.0, 0.0, -25.0). Use 'Initial\_Scale' to change size.

Initial\_Yaw= 600

Sets the initial yaw about the -z axis. Units in tenths of degrees. The default is zero (0). Positive angle gives CCW rotation.

Initial\_Roll= 100

Sets the initial roll about the x axis. Units in tenths of degrees. The default is zero (0). Positive angle gives CCW rotation.

Initial\_Scale= 0.75

Sets the initial scaling factor of the image. The default is one (1).

Camera\_Segment= 16

Sets the segment to which the camera is attached. The camera then moves with that segment. The default is zero (0).

Default\_Segment= 16

Sets the default segment to which any unattached planes are attached. The default is zero (0).

Light\_Direction= 0.0 1.0 -1.0

Sets the direction to the light. Assumed to be at infinity. The default is out the -z axis (0.0 0.0 -1.0).

Sensitivity= 3.0

Sets the sensitivity of the mouse movement. The default is two (2.0). The higher the number, the less mouse movement required.

#### INTERACTIVE COMMANDS:

The VCR-like commands may be chosen either by using the keyboard or the VCR front panel with the LEFT mouse button. The following is a list of the available functions, with the associated key shown in parentheses. Except for play, reverse, and quit, the program will reset to stop mode.

Play (F1)

Displays every frame in the data file in sequence, looping back to the beginning after the last frame. The speed of frame update is dependent on the speed of the machine and by the delay factor set with slower/faster buttons.

Reverse (F2)

Displays every frame in the data file in reverse sequence,

looping back to the end after the first frame. The speed of frame update is dependent on the speed of the machine and by the delay factor set with the slower/faster buttons.

StepFwd (F3)

Displays the next frame in the sequence. Loops back to the beginning after the last frame.

StepBwd (F4)

Displays the last frame in the sequence. Loops back to the end after the first frame.

Faster (F5)

Decrements the delay factor one step toward zero. Will never decrease past zero. Note that when the program is initialized the delay factor is set to zero, so it initially runs in its fastest mode.

Slower (F6)

Increments the delay factor by one step. Each increment slows down the frame rate by about 1/3 second, up to five increments.

Rewind (F7)

Sets the frame sequence back to the beginning. Also sets the delay factor back to zero.

Reset (F8)

Resets the rotations, translations, scaling factor, and the delay factor back to their initial values.

Stop (F9)

Stops the frame sequencing for both play and reverse.

Load (F10)

Asks for and loads a new data file and setup file.

Setup (F11)

Loads an easy-to-use file editor to modify the setup file without leaving the program. After quitting, the current setup file is read and the time is set to zero.

Quit (F12)

Quits the program, asks if OK.

MOUSE FUNCTIONALITY:

The mouse buttons have the following definitions:

LEFT

If the cursor is in the modeling screen, pressing and holding the left mouse button and moving the mouse toward the screen will zoom the image, while moving the mouse away from the screen

will shrink the image.

If the cursor is in a button on the VCR front panel, then that option will be chosen.

#### MIDDLE

Pressing and holding the middle mouse button will rotate the image about its local -Z axis if the mouse is moved to the left or right. It will rotate the image about its local X axis if the mouse is moved up or down.

#### RIGHT

Pressing and holding the right mouse button and moving the mouse up will move the image along the Z axis in the negative direction, while moving the mouse down will move the image along the Z axis in the positive direction. Moving the mouse to the right will move the image image along the X axis in the positive direction, while moving the mouse left will move the image along the X axis in the negative direction.

## APPENDIX B. EXAMPLE INPUT DECK (S9991.AIN)

[illegible]



LS Y	3	0	90.00	.00	.00	90.00	.00	.00	.00	62.50	.00	0	0	0	0	0	0	
			-.88	-7.38	-2.66	.00	.00	-5.43	0	.00	.00							CARD B.3
LE Z	14	-4	.00	90.00	.00	4.94	.00	.00	.00	.00	.00	.00	0	0	0	0	0	
			.00	.00	.00	90.00	.00	.00	.00	62.50	.00	0	0	0	0	0	0	CARD B.3
RW	13	-8	.00	.00	6.07	-.30	.00	-2.13	0	.00	.00							CARD B.3
			.00	.00	.00	90.00	.00	.00	.00	15.00	.00	0	0	0	0	0	0	CARD B.3
LW	15	-8	.00	.00	6.07	-.30	.00	-2.13	0	.00	.00							CARD B.3
			.00	.00	.00	90.00	.00	.00	.00	15.00	.00	0	0	0	0	0	0	CARD B.3
LR	20	1	10.50	-10.00	-31.75	.00	-6.50	.00	0	.00	.00							CARD B.3
			.00	.00	.00	90.00	-48.50	.00	.00	.00	.00	.00	0	0	0	0	0	CARD B.3
RR	20	1	10.50	-10.00	-31.75	.00	-6.50	.00	0	.00	.00							CARD B.3
			.00	.00	.00	90.00	-48.50	.00	.00	.00	.00	.00	0	0	0	0	0	CARD B.3
			.00	.00	.00	1.00	.00	34.38	.00	.00	1.00							.00CARD B.4
			.00	.00	.00	1.00	.00	34.38	.00	.00	1.00							.00CARD B.4
			.00	.00	.00	1.00	.00	15.00	.00	.00	1.00							.00CARD B.4
			.00	.00	.00	1.00	.00	15.00	.00	.00	1.00							.00CARD B.4
			.00	.00	.00	1.00	.00	7.50	75.00	75.00	1.00							55.00CARD B.4
			.00	2.32	.00	1.00	.00	48.90	.00	.00	1.00							.00CARD B.4
1.00	10.00	10.00	1.00	.00	.00	27.00	.00	6.69	.00	1.00								30.00CARD B.4
			.00	.00	.00	1.00	.00	.00	.00	.00								.00CARD B.4
			.00	.00	.00	1.00	.00	7.50	75.00	75.00	1.00							55.00CARD B.4
			.00	2.32	.00	1.00	.00	48.90	.00	.00	1.00							.00CARD B.4
1.00	10.00	10.00	1.00	.00	.00	27.00	.00	6.69	.00	1.00								30.00CARD B.4
			.00	.00	.00	1.00	.00	.00	.00	.00								.00CARD B.4
			.00	.00	.00	1.00	.00	.00100.00	100.00	1.00								125.00CARD B.4
			.00	20.00	20.00	1.00	.00	.00	4.65	.00	1.00							65.30CARD B.4
			.00	.00	.00	1.00	.00	.00	90.00	.00								.00CARD B.4
			.00	.00	.00	1.00	.00	.00100.00	100.00	1.00								125.00CARD B.4
			.00	20.00	20.00	1.00	.00	.00	4.65	.00	1.00							65.30CARD B.4
			.00	.00	.00	1.00	.00	.00	90.00	.00								.00CARD B.4
			.00	.00	.00	1.00	.00	.00	4.32	.14	1.00							55.50CARD B.4
			.00	.00	.00	1.00	.00	.00	.00	.00								.00CARD B.4
			.00	.00	.00	1.00	.00	.00	4.32	.14	1.00							55.50CARD B.4
			.00	.00	.00	1.00	.00	.00	.00	.00								.00CARD B.4
.00150.00	.00	.00	1.00	.00	.00	48.50	.00	.00	.00	1.00								.00CARD B.4
.00150.00	.00	.00	1.00	.00	.00	48.50	.00	.00	.00	1.00								.00CARD B.4
1.200	0.	30.	0.	0.	0.				0.	0.								CARD B.5
1.200	0.	30.	0.	0.	0.				0.	0.								CARD B.5
.350	0.	30.	0.	0.	0.				0.	0.								CARD B.5
.192	0.	30.	0.	0.	0.				0.	0.								CARD B.5
1.000	0.	30.	0.	0.	0.				0.	0.								CARD B.5
1.000	0.	30.	0.	0.	0.				0.	0.								CARD B.5
.500	0.	30.	0.	0.	0.				0.	0.								CARD B.5
.500	0.	30.	0.	0.	0.				0.	0.								CARD B.5
.000	0.	30.	0.	0.	0.				0.	0.								CARD B.5
1.000	0.	30.	0.	0.	0.				0.	0.								CARD B.5
1.000	0.	30.	0.	0.	0.				0.	0.								CARD B.5
.500	0.	30.	0.	0.	0.				0.	0.								CARD B.5
.500	0.	30.	0.	0.	0.				0.	0.								CARD B.5
.000	0.	30.	0.	0.	0.				0.	0.								CARD B.5
.100	0.	30.	0.	0.	0.				0.	0.								CARD B.5
.100	0.	30.	0.1	0.	0.				0.	0.								CARD B.5
.000	0.	30.	0.	0.	0.				0.	0.								CARD B.5
.100	0.	30.	0.	0.	0.				0.	0.								CARD B.5
.100	0.	30.	0.1	0.	0.				0.	0.								CARD B.5
.100	0.	30.	58.0	0.	0.				0.	0.								CARD B.5
.000	0.	30.	0.	0.	0.				0.	0.								CARD B.5
.500	0.	30.	0.	0.	0.				0.	0.								CARD B.5
.500	0.	30.	0.	0.	0.				0.	0.								CARD B.5
.000	0.	30.	0.	0.	0.				0.	0.								CARD B.5
.500	0.	30.	0.	0.	0.				0.	0.								CARD B.5
.500	0.	30.	0.	0.	0.				0.	0.								CARD B.5
.000	0.	30.	0.	0.	0.				0.	0.								CARD B.5
.0001	0.	30.	0.	0.	0.				0.	0.								CARD B.5
.0001	0.	30.	0.	0.	0.				0.	0.								CARD B.5
.01	.01	.01	.01	.01	.01	.01	.10	.10	.10	.10	.10	.10	.10	.10	.10	.10	.10	.01CARD B.6
.01	.01	.01	.00	.00	.00	.00	.10	.10	.10	.10	.00	.00	.00	.00	.00	.00	.00	.00CARD B.6
.01	.01	.01	.00	.00	.00	.00	.10	.10	.10	.00	.00	.00	.00	.00	.00	.00	.00	.00CARD B.6



1	HEAD SURFACE					CARD E.1
	.00	.71	-.80	.00	.00	CARD E.2
	2.57	-175.98	4495.67	-8953.11	6029.59	.00CARD E.3
3						CARD E.4
	.71	358.00	.75	3580.00	.80	35800.00CARD E.4
2	BACK OF SHOULDER					CARD E.1
	.00	1.62	-1.70	.00	.00	CARD E.2
	.01	-26.59	380.91	-678.22	456.53	.00CARD E.3
3						CARD E.4
	1.62	48.30	1.65	483.00	1.70	4830.00CARD E.4
3	CHEST					CARD E.1
	.00	1.31	-1.40	.00	.00	CARD E.2
	.55	5.46	73.49	-15.01	.00	.00CARD E.3
3						CARD E.4
	1.31	158.60	1.35	1586.00	1.40	15860.00CARD E.4
4	ANTERIOR PELVIS					CARD E.1
	.00	2.02	-2.10	.00	.00	CARD E.2
	-.14	1.58	24.39	-29.33	13.76	.00CARD E.3
3						CARD E.4
	2.02	89.70	2.05	897.00	2.10	8970.00CARD E.4
5	POSTERIOR PELVIS					CARD E.1
	.00	1.96	-2.10	.00	.00	CARD E.2
	-.76	35.10	40.04	-12.49	.00	.00CARD E.3
3						CARD E.4
	1.96	127.80	2.03	1278.00	2.10	12780.00CARD E.4
6	UPPER ARM					CARD E.1
	.00	.89	-1.00	.00	.00	CARD E.2
	1.54	-30.63	627.09	-1197.70	917.23	.00CARD E.3
3						CARD E.4
	.89	203.10	.95	2031.00	1.00	20310.00CARD E.4
7	FOREARM					CARD E.1
	.00	1.31	-1.40	.00	.00	CARD E.2
	-2.40	107.37	-313.36	504.61	-196.37	.00CARD E.3
3						CARD E.4
	1.31	156.20	1.35	1562.00	1.40	15620.00CARD E.4
8	HAND					CARD E.1
	.00	.38	-.45	.00	.00	CARD E.2
	-.04	-31.04	2384.47	-10193.90	19172.50	.00CARD E.3
3						CARD E.4
	.38	139.40	.41	1394.00	.45	13940.00CARD E.4
9	UPPER LEG					CARD E.1
	.00	1.31	-1.40	.00	.00	CARD E.2
	-.28	14.19	81.94	-122.62	98.73	-29.09CARD E.3
3						CARD E.4
	1.31	61.60	1.35	616.00	1.40	6160.00CARD E.4
10	KNEE					CARD E.1
	.00	.54	-.58	.00	.00	CARD E.2
	-.04	2.22	867.34	-401.61	.00	.00CARD E.3
3						CARD E.4
	.54	187.80	.56	1878.00	.58	18780.00CARD E.4
11	FRONT OF LOWER LEG					CARD E.1
	.00	1.78	-1.90	.00	.00	CARD E.2
	-.74	26.79	3.92	29.05	.00	.00CARD E.3
3						CARD E.4
	1.78	223.60	1.84	2236.00	1.90	22360.00CARD E.4
12	BACK OF LOWER LEG					CARD E.1
	.00	1.66	-1.75	.00	.00	CARD E.2
	-.08	29.42	-2.08	.00	.00	.00CARD E.3
3						CARD E.4
	1.66	43.20	1.70	432.00	1.75	4320.00CARD E.4
13	FOOT					CARD E.1
	.00	.83	-.95	.00	.00	CARD E.2
	-.68	82.75	-704.17	3367.10	-5570.69	3188.30CARD E.3
3						CARD E.4
	.83	121.20	.89	1212.00	.95	12120.00CARD E.4
14	SEAT CUSHION					CARD E.1
	0.0000000	-4.000000	.00000000	.00000000	1.00000000	CARD E.2
5						CARD E.4.a
	0.0000000	0.000000	1.0000000	60.000000	2.00000000	200.000000CARD E.4.b
	3.0000000	800.0000	4.0000000	2000.0000		CARD E.4.b

16	CONSTANT = 0.0					CARD E.1
	0.0000000	0.0000000	0.0000000	.00000000	0.00000000	CARD E.2
17	CONSTANT, F=0.9	0 0				CARD E.1
	0.0000000	0.0000000	0.9000000	0.0000000	0.00000000	CARD E.2
20	DAMPING COEFF. C=200	0 0				CARD E.1
	0.0000000	2.0000000	0.0000000	.00000000	1.00000000	CARD E.2
	0.0000000	200.00000	0.0000000	0.0000000	0.00000000	CARD E.3
21	RATE OF DEFLEC.	0 0				CARD E.1
	-40.0000000	-150.00000	.00000000	.00000000	1.00000000	CARD E.2
21						CARD E.4.a
	-40.0000000	.00000000	-30.0000000	.00000000	-20.0000000	.00000000
	-10.0000000	.00000000	.00000000	.00000000	5.00000000	1.00000000
	10.0000000	1.00000000	20.0000000	.989999900	30.0000000	.965000000
	40.0000000	.927999800	50.0000000	.860000100	60.0000000	.690000000
	70.0000000	.475000000	80.0000000	.340000000	90.0000000	.260000000
	100.000000	.200000000	110.000000	.180000000	120.000000	.090000000
	130.000000	.059999990	140.000000	.025000000	150.000000	.000000000
24	RESTRAINT BELT	0 0				CARD E.1
	0.0000000	-0.1000000	0.00000000	0.00000000	0.00000000	CARD E.2
6						CARD E.4.a
	0.0000000	0.00000000	0.01000000	165.000000	0.02000000	330.000000
	0.0300000	495.000000	0.05000000	935.000000	0.10000000	3850.000000
25	DECK-FOOT.	0 0				CARD E.1
	0.0000000	-1.3540000	0.00000000	0.00000000	1.00000000	CARD E.2
8						CARD E.4.a
	0.0000000	0.00000000	0.20000000	6.75000000	0.40100000	25.29000000
	0.6020000	48.7200000	0.80300000	101.790000	0.83400000	121.20000000
	0.9300000	1212.00000	1.35400000	12120.0000		
27	ARM RESTS.	0 0				CARD E.1
	0.0000000	-3.0000000	0.00000000	0.00000000	0.00000000	CARD E.2
6						CARD E.4.a
	0.0000000	0.00000000	0.10000000	100.000000	0.20000000	1000.000000
	1.0000000	5000.0000	2.00000000	10000.0000	3.00000000	15000.0000
28	CUSHION (REV2)					CARD E.1
	0.0000000	-6.0000000	0.00000000	0.00000000	1.00000000	CARD E.2
6						CARD E.4.a
	0.0000000	0.00000000	1.00000000	60.0000000	2.00000000	150.000000
	3.0000000	500.000000	4.00000000	2000.00000	6.00000000	10000.0000
29	CUSHION					CARD E.1
	0.0000000	-6.0000000	0.00000000	0.00000000	1.00000000	CARD E.2
6						CARD E.4.a
	0.0000000	0.00000000	1.00000000	50.0000000	2.00000000	125.000000
	3.0000000	250.000000	4.00000000	500.000000	6.00000000	1000.000000
30	CUSHION ABSORPTION					CARD E.1
	-1000.00	-1000.00000	0.00000000	0.00000000	1.00000000	CARD E.2
5						CARD E.4.a
	-1000.00	0.500000000	-6.0000000	0.50000000	-5.00000000	1.00000000
	0.0000000	1.000000000	1000.00000	1.00000000		
31	CUSHION VISCOUS					CARD E.1
	-2000.00	-2000.00000	0.00000000	0.00000000	1.00000000	CARD E.2
5						CARD E.4.a
	-2000.00	0.000000000	-200.00000	0.00000000	0.00000000	0.00000000
	200.0000	10.00000000	2000.00000	200.000000		
33	CONSTANT = 0.0					CARD E.1
	0.0000000	0.000000000	0.00000000	0.00000000	0.00000000	CARD E.2
34	DUMMY STIFFNESS					CARD E.1
	0.0000000	-4.0000000	0.00000000	0.00000000	0.00000000	CARD E.2
6						CARD E.4.a
	0.0000000	0.00000000	0.50000000	30.0000000	1.00000000	60.00000000
	1.5000000	90.0000000	1.80000000	900.000000	2.00000000	9000.000000
35	DUMMY ABSORPTION					CARD E.1
	-1000.00	-1000.0000	0.00000000	0.00000000	1.00000000	CARD E.2
5						CARD E.4.a
	-1000.00	0.460000000	-6.0000000	0.46000000	-5.00000000	1.00000000
	0.0000000	1.000000000	1000.00000	1.00000000		
36	ABDOMINAL VISCOUS					CARD E.1
	-2000.00	-2000.0000	0.00000000	0.00000000	1.00000000	CARD E.2
5						CARD E.4.a
	-2000.00	0.000000000	-200.00000	0.00000000	0.00000000	0.00000000
	200.0000	50.00000000	2000.00000	1000.00000		

37	CONSTANT F = 0.1					CARD E.1
0.000000	0.00000000	0.10000000	0.00000000	0.00000000		CARD E.2
9999						CARD E.1
41	RIGHT SHOULDER JOINT					CARD E.7
-4	8					CARD E.7
151.000	.000	87900.000	.000			
75.000	.000	13700.000	.000			
.000	.000	-312.000	11800.000			
66.000	.000	7780.000	3010000.000			
68.000	.000	22200.000	376000.000			
89.000	.000	22000.000	.000			
111.000	.000	2470.000	17600.000			
153.000	.000	13000.000	.000			
42	LEFT SHOULDER JOINT					CARD E.7
-4	8					CARD E.7
151.000	.000	87900.000	.000			
153.000	.000	13000.000	.000			
111.000	.000	2470.000	17600.000			
89.000	.000	22000.000	.000			
68.000	.000	22200.000	376000.000			
66.000	.000	7780.000	3010000.000			
.000	.000	-312.000	11800.000			
75.000	.000	13700.000	.000			
43	STANDING RIGHT HIP					CARD E.7
19	4					CARD E.7
.000	2.000	7.000	21.000	49.000	105.000	CARD E.7
217.000	441.000	889.000	1790.000	3580.000	7160.000	CARD E.7
14300.000	28700.000	57300.000	115000.000	229000.000	459000.000	CARD E.7
917000.000						
.000	5.000	11.000	22.000	39.000	73.000	CARD E.7
141.000	277.000	549.000	1090.000	2180.000	4360.000	CARD E.7
8710.000	17400.000	34800.000	69600.000	139000.000	279000.000	CARD E.7
557000.000						
.000	1.000	2.000	3.000	5.000	7.000	CARD E.7
10.000	13.000	17.000	22.000	27.000	32.000	CARD E.7
38.000	46.000	62.000	94.000	158.000	286.000	CARD E.7
542.000						
.000	1.000	3.000	4.000	6.000	8.000	CARD E.7
9.000	10.000	18.000	34.000	66.000	130.000	CARD E.7
258.000	514.000	1030.000	2050.000	4100.000	8190.000	CARD E.7
16400.000						
44	STANDING LEFT HIP					CARD E.7
19	4					CARD E.7
.000	2.000	7.000	21.000	49.000	105.000	CARD E.7
217.000	441.000	889.000	1790.000	3580.000	7160.000	CARD E.7
14300.000	28700.000	57300.000	115000.000	229000.000	459000.000	CARD E.7
917000.000						
.000	1.000	3.000	4.000	6.000	8.000	CARD E.7
9.000	10.000	18.000	34.000	66.000	130.000	CARD E.7
258.000	514.000	1030.000	2050.000	4100.000	8190.000	CARD E.7
16400.000						
.000	1.000	2.000	3.000	5.000	7.000	CARD E.7
10.000	13.000	17.000	22.000	27.000	32.000	CARD E.7
38.000	46.000	62.000	94.000	158.000	286.000	CARD E.7
542.000						
.000	5.000	11.000	22.000	39.000	73.000	CARD E.7
141.000	277.000	549.000	1090.000	2180.000	4360.000	CARD E.7
8710.000	17400.000	34800.000	69600.000	139000.000	279000.000	CARD E.7
557000.000						
45	STANDING LUMBAR SPIN					CARD E.7
19	4					CARD E.7
.000	1200.000	2400.000	3600.000	4800.000	6000.000	CARD E.7
7200.000	8400.000	9600.000	10800.000	13200.000	18000.000	CARD E.7
27600.000	46800.000	85200.000	162000.000	314600.000	622800.000	CARD E.7
1237200.000						

.000	1200.000	2400.000	3600.000	4800.000	6000.000	CARD E.7
7200.000	8400.000	9600.000	10800.000	13200.000	18000.000	CARD E.7
27600.000	46800.000	85200.000	162000.000	314600.000	622800.000	CARD E.7
1237200.000						
.000	960.000	1920.000	2880.000	3840.000	4800.000	CARD E.7
5760.000	6720.000	7680.000	8640.000	10560.000	14400.000	CARD E.7
22080.000	37440.000	68160.000	129600.000	252480.000	498240.000	CARD E.7
989760.000						
.000	1200.000	2400.000	3600.000	4800.000	6000.000	CARD E.7
7200.000	8400.000	9600.000	10800.000	13200.000	18000.000	CARD E.7
27600.000	46800.000	85200.000	162000.000	314600.000	622800.000	CARD E.7
7010800.000						

46 NECK PIVOT

CARD E.7

19	4					CARD E.7
.000	700.000	1400.000	2100.000	2800.000	3500.000	CARD E.7
4200.000	4900.000	5600.000	6300.000	7000.000	7700.000	CARD E.7
8400.000	9800.000	12600.000	18200.000	29400.000	51800.000	CARD E.7
96600.000						
.000	600.000	1200.000	1800.000	2400.000	3000.000	CARD E.7
3600.000	4200.000	4800.000	5400.000	6000.000	6600.000	CARD E.7
7200.000	8400.000	10800.000	15600.000	25200.000	44400.000	CARD E.7
82800.000						
.000	300.000	600.000	900.000	1200.000	1500.000	CARD E.7
1800.000	2100.000	2400.000	2700.000	3000.000	3300.000	CARD E.7
3600.000	4200.000	5400.000	7800.000	12600.000	22200.000	CARD E.7
41400.000						
.000	600.000	1200.000	1800.000	2400.000	3000.000	CARD E.7
3600.000	4200.000	4800.000	5400.000	6000.000	6600.000	CARD E.7
7200.000	8400.000	10800.000	15600.000	25200.000	44400.000	CARD E.7
82800.000						

47 HEAD PIVOT

CARD E.7

19	4					CARD E.7
.000	490.000	980.000	1680.000	2380.000	3080.000	CARD E.7
3780.000	4480.000	5180.000	5880.000	6580.000	7280.000	CARD E.7
7980.000	9380.000	12180.000	17780.000	28980.000	51380.000	CARD E.7
96180.000						
.000	600.000	1200.000	1800.000	2400.000	3000.000	CARD E.7
3600.000	4200.000	4800.000	5400.000	6000.000	6600.000	CARD E.7
7200.000	8400.000	10800.000	15600.000	25200.000	44400.000	CARD E.7
82800.000						
.000	250.000	500.000	800.000	1100.000	1400.000	CARD E.7
1700.000	2000.000	2300.000	2600.000	2900.000	3200.000	CARD E.7
3500.000	4100.000	5300.000	7700.000	12500.000	22100.000	CARD E.7
41300.000						
.000	600.000	1200.000	1800.000	2400.000	3000.000	CARD E.7
3600.000	4200.000	4800.000	5400.000	6000.000	6600.000	CARD E.7
7200.000	8400.000	10800.000	15600.000	25200.000	44400.000	CARD E.7
82800.000						

3	2	0	0	5	2	2	2	2		CARD F.1.a
1	20	1	1	14	-20	-21	-16	17	1	
1	20	6	6	14	-20	-21	-16	17	1	
1	20	9	9	14	-20	-21	-16	17	1	
2	20	7	7	14	-20	-21	-16	17	1	
2	20	10	10	14	-20	-21	-16	17	1	
5	20	1	1	28	-29	-30	-31	17	1	
5	20	2	2	28	-29	-30	-31	17	1	
5	20	3	3	28	-29	-30	-31	17	1	
5	20	12	12	28	-29	-30	-31	17	1	
5	20	14	14	28	-29	-30	-31	17	1	
6	20	4	4	14	-20	-21	-16	17	1	
6	20	5	5	14	-20	-21	-16	17	1	
7	20	12	12	14	-20	-21	-16	17	1	
7	20	13	13	14	-20	-21	-16	17	1	
8	20	15	15	14	-20	-21	-16	17	1	
8	20	14	14	14	-20	-21	-16	17	1	
9	20	8	8	25	0	0	0	17	-1	
9	20	11	11	25	0	0	0	17	-1	

F.2.a

1	20	1	1	24	0	0	0	1											F.2.b
4	4	4	0	4	5	2	0	4	1	0	0	3	0	2	0	0			4F.3
3																			F.3
1	1	13	13	33	-34	-35	-36	37											
1	1	15	15	33	-34	-35	-36	37											
1	1	16	16	33	-34	-35	-36	37											
1	1	17	17	33	-34	-35	-36	37											
2	2	6	6	33	-34	-35	-36	37											
2	2	9	9	33	-34	-35	-36	37											
2	2	17	17	33	-34	-35	-36	37											
2	2	16	16	33	-34	-35	-36	37											
3	3	13	13	33	-34	-35	-36	37											
3	3	15	15	33	-34	-35	-36	37											
3	3	6	6	33	-34	-35	-36	37											
3	3	9	9	33	-34	-35	-36	37											
5	5	13	13	33	-34	-35	-36	37											
5	5	15	15	33	-34	-35	-36	37											
5	5	16	16	33	-34	-35	-36	37											
5	5	17	17	33	-34	-35	-36	37											
6	6	12	12	33	-34	-35	-36	37											
6	6	13	13	33	-34	-35	-36	37											
6	6	16	16	33	-34	-35	-36	37											
6	6	9	9	33	-34	-35	-36	37											
6	6	17	17	33	-34	-35	-36	37											
7	7	10	10	33	-34	-35	-36	37											
7	7	11	11	33	-34	-35	-36	37											
9	9	15	15	33	-34	-35	-36	37											
9	9	14	14	33	-34	-35	-36	37											
9	9	16	16	33	-34	-35	-36	37											
9	9	17	17	33	-34	-35	-36	37											
10	10	8	8	33	-34	-35	-36	37											
13	13	15	15	33	-34	-35	-36	37											
13	13	17	17	33	-34	-35	-36	37											
13	13	2	2	33	-34	-35	-36	37											
15	15	16	16	33	-34	-35	-36	37											
15	15	2	2	33	-34	-35	-36	37											
18	18	3	3	27															

	0	3	.00000000	.00000000	.00000000	
	0	1	.00000000	.00000000	.00000000	
3	0	5	.00000000	.00000000	.00000000	H.3
	0	3	.00000000	.00000000	.00000000	
	0	1	.00000000	.00000000	.00000000	
1	0	5				H.4
1	0	5				H.5
1	3	5				H.6
2	17	18				H.7
0						H.8
						H.9
0						H.10
0	0					H.11



## **APPENDIX C. EXAMPLE OUTPUT FILE (S9991.AOU)**

## AAMRL ARTICULATED TOTAL BODY (ATB) MODEL

PAGE 1

DEVELOPED BY CALSPAN CORP., P.O. BOX 400, BUFFALO NY 14225  
AND BY J&J TECHNOLOGIES INC., ORCHARD PARK, NY 14127

FOR THE ARMSTRONG AEROSPACE MEDICAL RESEARCH LABORATORY  
WRIGHT PATTERSON AIR FORCE BASE  
UNDER CONTRACTS F3615-75C-5002, -78C-0516 AND -80C-05117

AND FOR THE NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION,  
U.S. DEPARTMENT OF TRANSPORTATION, UNDER CONTRACTS  
FH-11-7592, HS-053-2-485, HS-6-01300 AND HS-6-01410.

PROGRAM DOCUMENTATION: NHTSA REPORT NOS. DOT-HS-801-507  
THROUGH 510 (FORMERLY CALSPAN REPORT NO. ZQ-5180-L-1),  
AVAILABLE FROM NTIS (ACCESSION NOS. PB-241692, 3, 4 AND 5),  
APPENDIXES A-J TO THE ABOVE (AVAILABLE FROM CALSPAN),  
AND REPORT NOS. AMRL-TR-75-14 (NTIS NO. AD-A014 816),  
AFAMRL-TR-80-14 (NTIS NO. AD-A088 029), AND  
AFAMRL-TR-83-073 (NTIS NO. AD-B079 184).

THE MOST RECENT DOCUMENTATION IS IN REPORT NOS.  
AAMRL-TR-88-007 (NTIS NO. AD-A197 940),  
AAMRL-TR-88-009 (NTIS NO. AD-A198 726),  
AAMRL-TR-88-043 (NTIS NO. AD-A203 566).

PROGRAM ATBIV.4, (LATEST REVISION 04/14/94),  
EXECUTED ON A ABC COMPUTER  
AT XYZ COMPANY, CITY, STATE.

18 July 1997 IRSIN= 0 IRSOUT= 0 RSTIME = .0000

Seated 50% male Hybrid III. Shot 9991. Test B.

CARDS A

CARD A.1

CARD A.1.c

UNITL = IN.	UNITM = LB.	UNITT = SEC.	GRAVITY VECTOR = (	.0000,	.0000, 386.0880)	G = 386.0880
NDINT = 4	NSTEPS = 10	DT = .001000	H0 = .000020	HMAX = .000020	HMIN = .000005	

0 NPRT ARRAY



13	LS	Y	3	0	-880	-7.380	-2.660	.000	.000	-5.430	.00	90.00	.00	.00	.00
14	LE	Z	14	-4	.000	.000	4.940	.000	.000	-3.670	90.00	.00	90.00	.00	.00
15	RW		13	-8	.000	.000	6.070	-.300	.000	-2.130	90.00	.00	90.00	.00	.00
16	LW		15	-8	.000	.000	6.070	-.300	.000	-2.130	90.00	.00	90.00	.00	.00
17	LR		20	1	10.500	-10.000	-31.750	.000	.000	.000	90.00	.00	90.00	-48.50	.00
18	RR		20	1	-10.500	-10.000	-31.750	.000	.000	.000	90.00	.00	90.00	-48.50	.00
1 JOINT TORQUE CHARACTERISTICS															
3	PAGE														

CARDS B.4

## TORSIONAL SPRING CHARACTERISTICS

## FLEXURAL SPRING CHARACTERISTICS

JOINT	SPRING COEF. ( IN. LB./DEG**J)			ENERGY DISSIPATION COEF.	JOINT STOP (DEG)	SPRING COEF. ( IN. LB./DEG**J)			ENERGY DISSIPATION COEF.	JOINT STOP (DEG)
	LINEAR (J=1)	QUADRATIC (J=2)	CUBIC (J=3)			LINEAR (J=1)	QUADRATIC (J=2)	CUBIC (J=3)		
1	P	.000	.000	1.000	.000	34.380	.000	.000	1.000	.000
2	W	.000	.000	1.000	.000	34.380	.000	.000	1.000	.000
3	NP	.000	.000	1.000	.000	15.000	.000	.000	1.000	.000
4	HP	.000	.000	1.000	.000	15.000	.000	.000	1.000	.000
5	RH	.000	.000	1.000	.000	7.500	75.000	.000	1.000	.000
6	RK	.000	2.320	1.000	48.900	.000	.000	75.000	1.000	55.000
7	RA	1.000	10.000	1.000	27.000	.000	.000	.000	1.000	.000
		.000	.000	1.000	.000	.000	6.690	.000	1.000	30.000
8	LH	.000	.000	1.000	.000	7.500	75.000	75.000	1.000	55.000
9	LK	.000	2.320	1.000	48.900	.000	.000	.000	1.000	.000
10	LA	1.000	10.000	1.000	27.000	.000	6.690	.000	1.000	30.000
		.000	.000	1.000	.000					
11	RS	.000	.000	1.000	.000	.000	100.000	100.000	1.000	125.000
12	RE	.000	20.000	1.000	52.000	.000	4.650	.000	1.000	65.300
		.000	.000	1.000	.000					
13	LS	.000	.000	1.000	.000	.000	100.000	100.000	1.000	125.000
14	LE	.000	20.000	1.000	52.000	.000	4.650	.000	1.000	65.300
		.000	.000	1.000	.000					
15	RW	.000	.000	1.000	.000	.000	4.320	.140	1.000	55.500
		.000	.000	1.000	.000					
16	LW	.000	.000	1.000	.000	.000	4.320	.140	1.000	55.500
		.000	.000	1.000	.000					
17	LR	.000	150.000	1.000	48.500	.000	.000	.000	1.000	.000
18	RR	.000	150.000	1.000	48.500	.000	.000	.000	1.000	.000

CARDS B.5

## JOINT VISCOUS CHARACTERISTICS AND LOCK-UNLOCK CONDITIONS

JOINT	VISCOUS COEFFICIENT ( IN. LB.SEC./DEG)	COULOMB FRICTION ( IN. LB.)	FULL FRICTION ANGULAR VELOCITY (DEG/SEC.)	MAX TORQUE FOR A LOCKED JOINT ( IN. LB.)	MIN TORQUE FOR UNLOCKED JOINT ( IN. LB.)	MIN. ANG. VELOCITY FOR UNLOCKED JOINT (RAD/SEC.)	IMPULSE RESTITUTION COEFFICIENT
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1	P	1.200	30.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
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SEGMENT	INTEGRATION	CONVERGENCE	TEST	INPUT
1	1	1	1	1
2	1	1	1	1
3	1	1	1	1
4	1	1	1	1
5	1	1	1	1
6	1	1	1	1
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87	1	1	1	1
88	1	1	1	1
89	1	1	1	1
90	1	1	1	1
91	1	1	1	1
92	1	1	1	1
93	1	1	1	1
94	1	1	1	1

SEGMENT NO.	SYM	ANGULAR VELOCITIES (RAD/SEC.)			LINEAR VELOCITIES ( IN./SEC.)			ANGULAR ACCELERATIONS (RAD/SEC.**2)			LINEAR ACCELERATIONS ( IN./SEC.**2)		
		MAG. TEST	ABS. ERROR	REL. ERROR	MAG. TEST	ABS. ERROR	REL. ERROR	MAG. TEST	ABS. ERROR	REL. ERROR	MAG. TEST	ABS. ERROR	REL. ERROR
1	LT	.010	.010	.0100	.010	.010	.0100	.100	.100	.1000	.100	.100	.0100
2	MT	.010	.010	.0100	.000	.000	.0000	.100	.100	.1000	.000	.000	.0000
3	UT	.010	.010	.0100	.000	.000	.0000	.100	.100	.1000	.000	.000	.0000
4	N	.010	.010	.0100	.000	.000	.0000	.100	.100	.1000	.000	.000	.0000
5	H	.010	.010	.0100	.000	.000	.0000	.100	.100	.1000	.000	.000	.0000
6	RUL	.010	.010	.0100	.000	.000	.0000	.100	.100	.1000	.000	.000	.0000
7	RLL	.010	.010	.0100	.000	.000	.0000	.100	.100	.1000	.000	.000	.0000
8	RF	.010	.010	.0100	.000	.000	.0000	.100	.100	.1000	.000	.000	.0000

**CARDS B.6**

9	LUL	.010	.010	.0100	.000	.0000	.100	.100	.1000	.000	.000	.0000
10	LLL	.010	.010	.0100	.000	.0000	.100	.100	.1000	.000	.000	.0000
11	LF	.010	.010	.0100	.000	.0000	.100	.100	.1000	.000	.000	.0000
12	RUA	.010	.010	.0100	.000	.0000	.100	.100	.1000	.000	.000	.0000
13	RLA	.010	.010	.0100	.000	.0000	.100	.100	.1000	.000	.000	.0000
14	LUA	.010	.010	.0100	.000	.0000	.100	.100	.1000	.000	.000	.0000
15	LLA	.010	.010	.0100	.000	.0000	.100	.100	.1000	.000	.000	.0000
16	RHD	.010	.010	.0100	.000	.0000	.100	.100	.1000	.000	.000	.0000
17	LHD	.010	.010	.0100	.000	.0000	.100	.100	.1000	.000	.000	.0000
18	LAR	.010	.010	.0100	.000	.0000	.100	.100	.1000	.000	.000	.0000
19	RAR	.010	.010	.0100	.000	.0000	.100	.100	.1000	.000	.000	.0000
1 VEHICLE DECELERATION INPUTS												
5												PAGE

Shot 9991 - Sitting 50% Male Hybrid III - SSTV

CARDS C

MSEG	YAW	PITCH	ROLL	VIPS	VTIME	XO(X)	XO(Y)	XO(Z)	NATAB	ATO	ADT	I1 I3
0	.000	.000	.000	.000	.000	.000	.000	.000	.0000	.0000	.0000	0 0 0
VEHICLE LINEAR TIME HISTORY Shot 9991 - Sitting 50% Male Hybrid III - SSTV												

TIME (MSEC)	LINEAR DECELERATIONS (G'S)			LINEAR VELOCITIES (IN./SEC.)			LINEAR DISPLACEMENTS (IN.)		
	X	Y	Z	X	Y	Z	X	Y	Z
.000	.000	.003	-.001	.000	.000	.000	.000	.000	.000
.200	.000	.008	-.005	.000	.000	.000	.000	.000	.000
.400	.000	.014	.008	.000	.001	.000	.000	.000	.000
.600	.000	.010	.002	.000	.002	.000	.000	.000	.000
.800	.000	.006	.002	.000	.003	.000	.000	.000	.000
1.000	.000	.007	.002	.000	.003	-.001	.000	.000	.000

### Majority of vehicle excitation omitted for brevity.

1999.000	.000	.466	.055	.000	33.227	4.159	.000	7.537	-2.003
1999.200	.000	.432	.016	.000	33.192	4.156	.000	7.544	-2.002
1999.400	.000	.523	.035	.000	33.155	4.154	.000	7.551	-2.002
1999.600	.000	.568	.044	.000	33.113	4.151	.000	7.557	-2.001
1 VEHICLE ANGULAR TIME HISTORY Shot 9991 - Sitting 50% Male Hybrid III - SSTV									
228									PAGE

TIME (MSEC)	ANGULAR ACCELERATIONS (DEG/SEC.**2)			ANGULAR VELOCITIES (DEG/SEC.)			ANGULAR DISPLACEMENTS (DEG)		
	X	Y	Z	X	Y	Z	YAW	PITCH	ROLL
.000	.571	-.296	.000	.000	.000	.000	.000	.000	.000
.200	.380	.625	.000	.000	.000	.000	.000	.000	.000

.400	-1.776	3.212	.000	.000	.000
.600	-1.128	1.287	.000	.001	.000
.800	-.808	.451	.000	-.001	.000

**Majority of vehicle excitation omitted for brevity.**

1999.000	-63.241	-51.779	.000	-5.798	3.425	.000	-230	4.014	-5.557
1999.200	-60.558	-60.750	.000	-5.810	3.414	.000	-230	4.015	-5.558
1999.400	-61.659	-61.353	.000	-5.822	3.402	.000	-230	4.016	-5.559
1999.600	-62.550	-68.194	.000	-5.835	3.389	.000	-230	4.016	-5.560
VEHICLE PATHS TO GROUND									
PAGE									

451

THE GROUND (INERTIAL) SEGMENT IS REPRESENTED HERE BY A 0. . . THE COORD CATEGORY REFERS TO THE COORDINATE SYSTEM IN WHICH THE VEHICLE DATA ARE SPECIFIED. A NEGATIVE VALUE FOR COORD INDICATES THAT THE DATA REPRESENT ACCELEROMETER DATA.

```

VEH  COORD  VEHICLE PATH TO GROUND
VEH  GRND  GRND
20  0      0

```

[illegible]

131

POINT 2 9.5000 -9.2500 -24.5000  
 POINT 3 9.5000 9.2500 -19.7500  
 0 PLANE NO. 5 Seat Back.

POINT 1 X Y Z  
 POINT 2 -9.5000 -8.3000 -28.2500  
 POINT 3 9.5000 -8.3000 -28.2500  
 0 PLANE NO. 6 Seat Back. Top.

POINT 1 X Y Z  
 POINT 2 -9.5000 -10.2500 -44.5500  
 POINT 3 9.5000 -10.2500 -44.5500  
 0 PLANE NO. 7 Seat Back. Right Si

POINT 1 X Y Z  
 POINT 2 -9.5000 -12.2700 -27.7700  
 POINT 3 9.5000 -8.3000 -28.2500  
 1 PLANE INPUTS  
 453

0 PLANE NO. 8 Seat Back. Left Sid

POINT 1 X Y Z  
 POINT 2 9.5000 -12.2700 -27.7700  
 POINT 3 9.5000 -14.2200 -44.0700  
 0 PLANE NO. 9 Deck.

POINT 1 X Y Z  
 POINT 2 -25.0000 -25.0000 .0000  
 POINT 3 25.0000 25.0000 .0000  
 1 BELT INPUTS  
 454

0 BELT NO. 1 LAP BELT

ANCHOR POINT A  
 X Y Z  
 -9.500 -9.500 -24.500

FIXED POINT ON SEGMENT  
 X Y Z  
 2.720 .000 -4.030

0 BODY SEGMENT SYMMETRY INPUT

ANCHOR POINT B  
 X Y Z  
 9.500 -9.500 -24.500

SLACK(+) LENGTH(-)  
 .000 -.100

PAGE

CARDS D.2

PAGE

CARDS D.3

CARD D.7



SEG NO. 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19  
 0 NSYM(J) 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0  
 1  
 455

PAGE  
 CARDS E

NTI( 1) = 1

FUNCTION NO. 1 HEAD SURFACE

D0 .0000 D1 .7100 D2 -.8000 D3 .0000 D4 .0000

FIRST PART OF FUNCTION - 5TH DEGREE POLYNOMIAL

A0 2.570000 A1 -175.980000 A2 4495.670000 A3 -8953.110000 A4 6029.590000 A5 .000000

SECOND PART OF FUNCTION - 3 TABULAR POINTS

D F(D)  
 .710000 358.0000  
 .750000 3580.0000  
 .800000 35800.0000

FUNCTION NO. 2 BACK OF SHOULDER

NTI( 2) = 19

D0 .0000 D1 1.6200 D2 -1.7000 D3 .0000 D4 .0000

FIRST PART OF FUNCTION - 5TH DEGREE POLYNOMIAL

A0 .010000 A1 -26.590000 A2 380.910000 A3 -678.220000 A4 456.530000 A5 .000000

SECOND PART OF FUNCTION - 3 TABULAR POINTS

D F(D)  
 1.620000 48.3000  
 1.650000 483.0000  
 1.700000 4830.0000

CARDS E

1  
456

FUNCTION NO. 3 CHEST

PAGE  
CARDS E

				NTI ( 3 ) = 37	
D0	D1	D2	D3	D4	
.0000	1.3100	-1.4000	.0000	.0000	

FIRST PART OF FUNCTION - 5TH DEGREE POLYNOMIAL

A0	A1	A2	A3	A4	A5
.550000	5.460000	73.490000	-15.010000	.000000	.000000

SECOND PART OF FUNCTION - 3 TABULAR POINTS

D	F(D)
1.310000	158.6000
1.350000	1586.0000
1.400000	15860.0000

134

FUNCTION NO. 4 ANTERIOR PELVIS

CARDS E

				NTI ( 4 ) = 55	
D0	D1	D2	D3	D4	
.0000	2.0200	-2.1000	.0000	.0000	

FIRST PART OF FUNCTION - 5TH DEGREE POLYNOMIAL

A0	A1	A2	A3	A4	A5
-.140000	1.580000	24.390000	-29.330000	13.760000	.000000

SECOND PART OF FUNCTION - 3 TABULAR POINTS

D	F(D)
2.020000	89.7000
2.050000	897.0000
2.100000	8970.0000

1  
457

FUNCTION NO. 5 POSTERIOR PELVIS

PAGE  
CARDS E

NTI ( 5 ) = 73

D0	D1	D2	D3	D4
.0000	1.9600	-2.1000	.0000	.0000

FIRST PART OF FUNCTION - 5TH DEGREE POLYNOMIAL

A0	A1	A2	A3	A4	A5
-.760000	35.100000	40.040000	-12.490000	.000000	.000000

SECOND PART OF FUNCTION - 3 TABULAR POINTS

D	F(D)
1.960000	127.8000
2.030000	1278.0000
2.100000	12780.0000

FUNCTION NO. 6 UPPER ARM NTI( 6) = 91 CARDS E

D0	D1	D2	D3	D4
.0000	.8900	-1.0000	.0000	.0000

FIRST PART OF FUNCTION - 5TH DEGREE POLYNOMIAL

A0	A1	A2	A3	A4	A5
1.540000	-30.630000	627.090000	-1197.700000	917.230000	.000000

SECOND PART OF FUNCTION - 3 TABULAR POINTS

D	F(D)
.890000	203.1000
.950000	2031.0000
1.000000	20310.0000

1  
458  
FUNCTION NO. 7 FOREARM NTI( 7) = 109 PAGE CARDS E

D0	D1	D2	D3	D4
.0000	1.3100	-1.4000	.0000	.0000

FIRST PART OF FUNCTION - 5TH DEGREE POLYNOMIAL

A0	A1	A2	A3	A4	A5
-2.400000	107.370000	-313.360000	504.610000	-196.370000	.000000

SECOND PART OF FUNCTION - 3 TABULAR POINTS

D	F(D)
1.310000	156.2000
1.350000	1562.0000
1.400000	15620.0000

FUNCTION NO. 8 HAND

NTI( 8) = 127

CARDS E

D0	D1	D2	D3	D4
.0000	.3800	-.4500	.0000	.0000

FIRST PART OF FUNCTION - 5TH DEGREE POLYNOMIAL

A0	A1	A2	A3	A4	A5
-.040000	-31.040000	2384.470000	-10193.900000	19172.500000	.000000

SECOND PART OF FUNCTION - 3 TABULAR POINTS

D	F(D)
.380000	139.4000
.410000	1394.0000
.450000	13940.0000

1  
459

FUNCTION NO. 9 UPPER LEG

NTI( 9) = 145

PAGE

CARDS E

D0	D1	D2	D3	D4
.0000	1.3100	-1.4000	.0000	.0000

FIRST PART OF FUNCTION - 5TH DEGREE POLYNOMIAL

A0	A1	A2	A3	A4	A5
-.280000	14.190000	81.940000	-122.620000	98.730000	-29.090000

SECOND PART OF FUNCTION - 3 TABULAR POINTS

D	F(D)
1.310000	61.6000
1.350000	616.0000
1.400000	6160.0000

FUNCTION NO. 10 KNEE NTI(10) = 163 CARDS E

D0	D1	D2	D3	D4
.0000	.5400	-.5800	.0000	.0000

FIRST PART OF FUNCTION - 5TH DEGREE POLYNOMIAL

A0	A1	A2	A3	A4	A5
-.040000	2.220000	867.340000	-401.610000	.000000	.000000

SECOND PART OF FUNCTION - 3 TABULAR POINTS

D	F(D)
.540000	187.8000
.560000	1878.0000
.580000	18780.0000

1 460 FUNCTION NO. 11 FRONT OF LOWER LEG NTI(11) = 181 PAGE CARDS E

D0	D1	D2	D3	D4
.0000	1.7800	-1.9000	.0000	.0000

FIRST PART OF FUNCTION - 5TH DEGREE POLYNOMIAL

A0	A1	A2	A3	A4	A5
-.740000	26.790000	3.920000	29.050000	.000000	.000000

SECOND PART OF FUNCTION - 3 TABULAR POINTS

D F(D)  
 1.780000 223.6000  
 1.840000 2236.0000  
 1.900000 22360.0000

FUNCTION NO. 12 BACK OF LOWER LEG NTI(12) = 199 CARDS E

D0 .0000 D1 1.6600 D2 -1.7500 D3 .0000 D4 .0000

FIRST PART OF FUNCTION - 5TH DEGREE POLYNOMIAL

A0 -.080000 A1 29.420000 A2 -2.080000 A3 .000000 A4 .000000 A5 .000000

SECOND PART OF FUNCTION - 3 TABULAR POINTS

D F(D)  
 1.660000 43.2000  
 1.700000 432.0000  
 1.750000 4320.0000

1  
 461

FUNCTION NO. 13 FOOT NTI(13) = 217 PAGE CARDS E

D0 .0000 D1 .8300 D2 -.9500 D3 .0000 D4 .0000

FIRST PART OF FUNCTION - 5TH DEGREE POLYNOMIAL

A0 -.680000 A1 82.750000 A2 -704.170000 A3 3367.100000 A4 -5570.690000 A5 3188.300000

SECOND PART OF FUNCTION - 3 TABULAR POINTS

D F(D)  
 .830000 121.2000  
 .890000 1212.0000  
 .950000 12120.0000

CARDS E

FUNCTION NO. 14 SEAT CUSHION NTI(14) = 235  
D0 .0000 D1 -4.0000 D2 .0000 D3 .0000 D4 1.0000

FIRST PART OF FUNCTION - 5 TABULAR POINTS

D .000000  
1.000000  
2.000000  
3.000000  
4.000000  
F(D)  
.0000  
60.0000  
200.0000  
800.0000  
2000.0000

1  
462

FUNCTION NO. 16 CONSTANT = 0.0  
CARDS E

PAGE

NTI(16) = 251

139

D0 .0000 D1 .0000 D2 .0000 D3 .0000 D4 .0000

FUNCTION IS CONSTANT .000000

CARDS E

FUNCTION NO. 17 CONSTANT, F=0.9 NTI(17) = 256  
D0 .0000 D1 .0000 D2 .9000 D3 .0000 D4 .0000

FUNCTION IS CONSTANT .900000

1  
463

FUNCTION NO. 20 DAMPING COEFF. C=200 NTI(20) = 261  
D0 .0000 D1 .0000 D2 .0000 D3 .0000 D4 .0000

PAGE

CARDS E

.0000                    2.0000                    .0000                    1.0000

FIRST PART OF FUNCTION - 5TH DEGREE POLYNOMIAL

A0	A1	A2	A3	A4	A5
.000000	200.000000	.000000	.000000	.000000	.000000

FUNCTION NO. 21      RATE OF DEFLEC.      NTI(21) = 272      CARDS E

D0	D1	D2	D3	D4
-40.0000	-150.0000	.0000	.0000	1.0000

FIRST PART OF FUNCTION - 21 TABULAR POINTS

D	F(D)
-40.000000	.0000
-30.000000	.0000
-20.000000	.0000
-10.000000	.0000
.000000	.0000
5.000000	1.0000
10.000000	1.0000
20.000000	.9900
30.000000	.9650
40.000000	.9280
50.000000	.8600
60.000000	.6900
70.000000	.4750
80.000000	.3400
90.000000	.2600
100.000000	.2000
110.000000	.1800
120.000000	.0900
130.000000	.0600
140.000000	.0250
150.000000	.0000

1  
464  
FUNCTION NO. 24      RESTRAINT BELT      NTI(24) = 320      PAGE  
CARDS E



D0	D1	D2	D3	D4
.0000	-.1000	.0000	.0000	.0000

FIRST PART OF FUNCTION - 6 TABULAR POINTS

D	F (D)
.000000	.0000
.010000	165.0000
.020000	330.0000
.030000	495.0000
.050000	935.0000
.100000	3850.0000

CARDS E

FUNCTION NO.	25	DECK-FOOT.	0	NTI (25) =	338
D0	.0000	D1	D2	D3	D4
		-1.3540	.0000	.0000	1.0000

FIRST PART OF FUNCTION - 8 TABULAR POINTS

D	F (D)
.000000	.0000
.200000	6.7500
.401000	25.2900
.602000	48.7200
.803000	101.7900
.834000	121.2000
.930000	1212.0000
1.354000	12120.0000

PAGE

CARDS E

FUNCTION NO.	27	ARM RESTS.	0	NTI (27) =	360
D0	.0000	D1	D2	D3	D4
		-3.0000	.0000	.0000	.0000

FIRST PART OF FUNCTION - 6 TABULAR POINTS

D	F (D)
---	-------

.000000  
 .100000  
 .200000  
 1.000000  
 2.000000  
 3.000000

FUNCTION NO. 28 CUSHION (REV2)  
 CARDS E

NTI (28) = 378

D0 .0000 D1 -6.0000 D2 .0000 D3 .0000 D4 1.0000

FIRST PART OF FUNCTION - 6 TABULAR POINTS

D F(D)  
 .000000 .0000  
 1.000000 60.0000  
 2.000000 150.0000  
 3.000000 500.0000  
 4.000000 2000.0000  
 6.000000 10000.0000

1  
 466  
 FUNCTION NO. 29 CUSHION  
 396

PAGE  
 NTI (29) =

CAR

CARDS E

D0 .0000 D1 -6.0000 D2 .0000 D3 .0000 D4 1.0000

FIRST PART OF FUNCTION - 6 TABULAR POINTS

D F(D)  
 .000000 .0000  
 1.000000 50.0000  
 2.000000 125.0000  
 3.000000 250.0000  
 4.000000 500.0000  
 6.000000 1000.0000

FUNCTION NO. 30 CUSHION ABSORPTION NTI (30) = 414  
CARDS E

D0	D1	D2	D3	D4
-1000.0000	-1000.0000	.0000	.0000	1.0000

FIRST PART OF FUNCTION - 5 TABULAR POINTS

D	F (D)
-1000.000000	.5000
-6.000000	.5000
-5.000000	1.0000
.000000	1.0000
1000.000000	1.0000

1  
467

FUNCTION NO. 31 CUSHION VISCOUS  
CARDS E

NTI (31) = 430

PAGE

D0	D1	D2	D3	D4
-2000.0000	-2000.0000	.0000	.0000	1.0000

FIRST PART OF FUNCTION - 5 TABULAR POINTS

D	F (D)
-2000.000000	.0000
-200.000000	.0000
.000000	.0000
200.000000	10.0000
2000.000000	200.0000

FUNCTION NO. 33 CONSTANT = 0.0  
CARDS E

NTI (33) = 446

D0	D1	D2	D3	D4
.0000	.0000	.0000	.0000	.0000

1  
468  
FUNCTION NO. 34 DUMMY STIFFNESS  
CARDS E

FUNCTION IS CONSTANT .000000

NTI (34) = 451

PAGE

D0	D1	D2	D3	D4
.0000	-4.0000	.0000	.0000	.0000

FIRST PART OF FUNCTION - 6 TABULAR POINTS

D	F (D)
.000000	.0000
.500000	30.0000
1.000000	60.0000
1.500000	90.0000
1.800000	900.0000
2.000000	9000.0000

144  
FUNCTION NO. 35 DUMMY ABSORPTION  
CARDS E

NTI (35) = 469

D0	D1	D2	D3	D4
-1000.0000	-1000.0000	.0000	.0000	1.0000

FIRST PART OF FUNCTION - 5 TABULAR POINTS

D	F (D)
-1000.000000	.4600
-6.000000	.4600
-5.000000	1.0000
.000000	1.0000
1000.000000	1.0000

1  
469  
FUNCTION NO. 36 ABDOMINAL VISCOUS  
CARDS E

NTI (36) = 485

PAGE

D0	D1	D2	D3	D4
-2000.0000	-2000.0000	.0000	.0000	1.0000

FIRST PART OF FUNCTION - 5 TABULAR POINTS

D	F(D)
-2000.000000	.0000
-200.000000	.0000
.000000	.0000
200.000000	50.0000
2000.000000	1000.0000

FUNCTION NO. 37    CONSTANT F = 0.1    NTI(37) = 501  
CARDS E

D0	D1	D2	D3	D4
.0000	.0000	.1000	.0000	.0000

FUNCTION IS CONSTANT .100000  
1 JOINT FORCE FUNCTION NO. 41    RIGHT SHOULDER JOINT    NTI(41) = 506  
470

PAGE  
CARDS E.7

0 FUNCTION IS COEFFICIENTS OF 3 ORDER POLYNOMIALS IN (THETA-THETA0) FOR 8 VALUES OF PHI.

PHI	THETA0	COEFFICIENTS OF (THETA-THETA0)**N	
		N = 1	N = 2
-180.00	151.000	.0000000	87900.00
-135.00	75.000	.0000000	13700.00
-90.00	.000	.0000000	-312.0000
-45.00	66.000	.0000000	7780.000
.00	68.000	.0000000	22200.00
45.00	89.000	.0000000	22000.00
90.00	111.000	.0000000	2470.000
135.00	153.000	.0000000	13000.00

1 JOINT FORCE FUNCTION NO. 42    LEFT SHOULDER JOINT    NTI(42) = 545  
471

PAGE  
CARDS E.7





DO .0000	D1 .0000	D2 .0000	D3 .0000	REF. SEGMENT .0000	NTI (46) = 833
-180.00	.000	160.000	170.000	180.000	6000.000
		1200.000	2400.000	3600.000	13200.00
		7200.000	8400.000	9600.000	162000.0
		18000.00	27600.00	46800.00	
		314600.0	622800.0	1237200.	
-90.00	.000	1200.000	2400.000	3600.000	6000.000
		7200.000	8400.000	9600.000	13200.00
		18000.00	27600.00	46800.00	162000.0
		314600.0	622800.0	1237200.	
.00	.000	960.0000	1920.000	2880.000	4800.000
		5760.000	6720.000	7680.000	10560.00
		14400.00	22080.00	37440.00	129600.0
		252480.0	498240.0	989760.0	
90.00	.000	1200.000	2400.000	3600.000	6000.000
		7200.000	8400.000	9600.000	13200.00
		18000.00	27600.00	46800.00	162000.0
		314600.0	622800.0	7010800.	

1 JOINT FORCE FUNCTION NO. 46 NECK PIVOT  
475

PAGE  
CARDS E.7

0 FUNCTION IS TABULAR FOR 19 X 4 VALUES OF THETA AND PHI

PHI	THETA0	THETA			
		10.000	60.000	110.000	160.000
-180.00	.000	700.0000	4200.000	7700.000	29400.00
		4200.000	7700.000	600.0000	3600.000
		6600.000	25200.00	300.0000	6000.000
-90.00	.000	700.0000	4200.000	7700.000	29400.00
		4200.000	7700.000	600.0000	3600.000
		6600.000	25200.00	300.0000	6000.000
.00	.000	700.0000	4200.000	7700.000	29400.00
		4200.000	7700.000	600.0000	3600.000
		6600.000	25200.00	300.0000	6000.000
90.00	.000	700.0000	4200.000	7700.000	29400.00
		4200.000	7700.000	600.0000	3600.000
		6600.000	25200.00	300.0000	6000.000



1 JOINT FORCE FUNCTION NO. 47 HEAD PIVOT  
 476

6600.000 7200.000 8400.000 10800.00 15600.00  
 25200.00 44400.00 82800.00

NTI(47) = 916

PAGE  
 CARDS E.7

D0 .0000 D1 .0000 D2 .0000 D3 .0000 REF. SEGMENT .0000

0 FUNCTION IS TABULAR FOR 19 X 4 VALUES OF THETA AND PHI

PHI	THETA	THETA	10.000	20.000	30.000	40.000	50.000
-180.00	.000	490.0000	3780.000	4480.000	5180.000	5880.000	6580.000
		3780.000	7280.000	7980.000	9380.000	12180.00	17780.00
		28980.00	51380.00	51380.00	96180.00		
		600.0000	1200.000	1800.000	2400.000	3000.000	3600.000
-90.00	.000	3600.000	4200.000	4800.000	5400.000	6000.000	6600.000
		6600.000	7200.000	8400.000	10800.00	15600.00	
		25200.00	44400.00	82800.00			
		250.0000	500.0000	800.0000	1100.000	1400.000	1700.000
90.00	.000	1700.000	2000.000	2300.000	2600.000	2900.000	3200.000
		3200.000	3500.000	4100.000	5300.000	7700.000	
		12500.00	22100.00	41300.00			
		600.0000	1200.000	1800.000	2400.000	3000.000	3600.000
		6600.000	7200.000	8400.000	10800.00	15600.00	

1 ALLOWED CONTACTS AND ASSOCIATED FUNCTIONS

PLANE	SEGMENT	FORCE DEFLECTION	INERTIAL SPIKE	R FACTOR	G FACTOR	FRICTION COEF.	CARDS F.1
0	1- 1	14	-20	-21	-16	17	1
0	1- 20	Botto LT SEAT CUSHION CONSTANT, F=0.9	DAMPING COEFF. C=200 RATE OF DEFLEC.		CONSTANT = 0.0		
0	6- 6	14	-20	-21	-16	17	1
0	1- 20	Botto RUL SEAT CUSHION CONSTANT, F=0.9	DAMPING COEFF. C=200 RATE OF DEFLEC.		CONSTANT = 0.0		
0	9- 9	14	-20	-21	-16	17	1
0	1- 20	Botto LUL SEAT CUSHION CONSTANT, F=0.9	DAMPING COEFF. C=200 RATE OF DEFLEC.		CONSTANT = 0.0		

0	2- 20	Front RLI SEAT CUSHION CONSTANT, F=0.9	7- 7 10- 10	14	-20	-21	-16	17	1
0	2- 20	Front LLL SEAT CUSHION CONSTANT, F=0.9	10- 10	14	-20	-21	-16	17	1
0	5- 20	LT CUSHION (REV2) CAR CUSHION ABSORPTION	1- 1	28	-29	-30	-31	17	1
F=0.9	Seat Back.								CONSTANT,
0	5- 20	MT CUSHION (REV2) CAR CUSHION ABSORPTION	2- 2	28	-29	-30	-31	17	1
F=0.9	Seat Back.								CONSTANT,
0	5- 20	UT CUSHION (REV2) CAR CUSHION ABSORPTION	3- 3	28	-29	-30	-31	17	1
F=0.9	Seat Back.								CONSTANT,
0	5- 20	RUA CUSHION (REV2) CAR CUSHION ABSORPTION	12- 12	28	-29	-30	-31	17	1
F=0.9	Seat Back.								CONSTANT,
0	5- 20	LUA CUSHION (REV2) CAR CUSHION ABSORPTION	14- 14	28	-29	-30	-31	17	1
F=0.9	Seat Back.								CONSTANT,
0	6- 20	Top. N SEAT CUSHION CONSTANT, F=0.9	4- 4	14	-20	-21	-16	17	1
0	6- 20	Top. H SEAT CUSHION CONSTANT, F=0.9	5- 5	14	-20	-21	-16	17	1
0	7- 20	Right Si RUA SEAT CUSHION CONSTANT, F=0.9	12- 12	14	-20	-21	-16	17	1
0	7- 20	Right Si RLA SEAT CUSHION CONSTANT, F=0.9	13- 13	14	-20	-21	-16	17	1
0	8- 20	Left Sid LLA SEAT CUSHION CONSTANT, F=0.9	15- 15	14	-20	-21	-16	17	1
0	8- 20	Left Sid LUA SEAT CUSHION CONSTANT, F=0.9	14- 14	14	-20	-21	-16	17	1
0	9- 20	RF DECK-FOOT.	8- 8	25	0	0	0	17	-1
0	9- 20	LF DECK-FOOT.	11- 11	25	0	0	0	17	-1

0	BELT	SEGMENT	FORCE DEFLECTION	INERTIAL SPIKE	R FACTOR	G FACTOR	C LT RESTRAINT BELT	CARDS F.2 FRICTION COEF.
0	OPT	1- 1	24	0	0	0	0	1
0	LAP BELT HEAD SURFACE							
0	0	1- 1	33	-34	-35	DUMMY STIFFNESS CONSTANT F = 0.1	-36	37
0	0	13- 13	33	ABDOMINAL VISCIOUS				0
0	0	15- 15	33	-34	-35	DUMMY STIFFNESS CONSTANT F = 0.1	-36	37
0	0	17- 17	33	ABDOMINAL VISCIOUS				0
0	0	19- 19	33	-34	-35	DUMMY STIFFNESS CONSTANT F = 0.1	-36	37
0	0	21- 21	33	ABDOMINAL VISCIOUS				0
0	0	23- 23	33	-34	-35	DUMMY STIFFNESS CONSTANT F = 0.1	-36	37
0	0	25- 25	33	ABDOMINAL VISCIOUS				0
0	0	27- 27	33	-34	-35	DUMMY STIFFNESS CONSTANT F = 0.1	-36	37
0	0	29- 29	33	ABDOMINAL VISCIOUS				0
0	0	31- 31	33	-34	-35	DUMMY STIFFNESS CONSTANT F = 0.1	-36	37
0	0	33- 33	33	ABDOMINAL VISCIOUS				0
0	0	35- 35	33	-34	-35	DUMMY STIFFNESS CONSTANT F = 0.1	-36	37
0	0	37- 37	33	ABDOMINAL VISCIOUS				0
0	0	39- 39	33	-34	-35	DUMMY STIFFNESS CONSTANT F = 0.1	-36	37
0	0	41- 41	33	ABDOMINAL VISCIOUS				0
0	0	43- 43	33	-34	-35	DUMMY STIFFNESS CONSTANT F = 0.1	-36	37
0	0	45- 45	33	ABDOMINAL VISCIOUS				0
0	0	47- 47	33	-34	-35	DUMMY STIFFNESS CONSTANT F = 0.1	-36	37
0	0	49- 49	33	ABDOMINAL VISCIOUS				0
0	0	51- 51	33	-34	-35	DUMMY STIFFNESS CONSTANT F = 0.1	-36	37
0	0	53- 53	33	ABDOMINAL VISCIOUS				0
0	0	55- 55	33	-34	-35	DUMMY STIFFNESS CONSTANT F = 0.1	-36	37
0	0	57- 57	33	ABDOMINAL VISCIOUS				0
0	0	59- 59	33	-34	-35	DUMMY STIFFNESS CONSTANT F = 0.1	-36	37
0	0	61- 61	33	ABDOMINAL VISCIOUS				0
0	0	63- 63	33	-34	-35	DUMMY STIFFNESS CONSTANT F = 0.1	-36	37
0	0	65- 65	33	ABDOMINAL VISCIOUS				0
0	0	67- 67	33	-34	-35	DUMMY STIFFNESS CONSTANT F = 0.1	-36	37
0	0	69- 69	33	ABDOMINAL VISCIOUS				0
0	0	71- 71	33	-34	-35	DUMMY STIFFNESS CONSTANT F = 0.1	-36	37
0	0	73- 73	33	ABDOMINAL VISCIOUS				0
0	0	75- 75	33	-34	-35	DUMMY STIFFNESS CONSTANT F = 0.1	-36	37
0	0	77- 77	33	ABDOMINAL VISCIOUS				0
0	0	79- 79	33	-34	-35	DUMMY STIFFNESS CONSTANT F = 0.1	-36	37
0	0	81- 81	33	ABDOMINAL VISCIOUS				0
0	0	83- 83	33	-34	-35	DUMMY STIFFNESS CONSTANT F = 0.1	-36	37
0	0	85- 85	33	ABDOMINAL VISCIOUS				0
0	0	87- 87	33	-34	-35	DUMMY STIFFNESS CONSTANT F = 0.1	-36	37
0	0	89- 89	33	ABDOMINAL VISCIOUS				0
0	0	91- 91	33	-34	-35	DUMMY STIFFNESS CONSTANT F = 0.1	-36	37
0	0	93- 93	33	ABDOMINAL VISCIOUS				0
0	0	95- 95	33	-34	-35	DUMMY STIFFNESS CONSTANT F = 0.1	-36	37
0	0	97- 97	33	ABDOMINAL VISCIOUS				0
0	0	99- 99	33	-34	-35	DUMMY STIFFNESS CONSTANT F = 0.1	-36	37
0	0	101- 101	33	ABDOMINAL VISCIOUS				0
0	0	103- 103	33	-34	-35	DUMMY STIFFNESS CONSTANT F = 0.1	-36	37
0	0	105- 105	33	ABDOMINAL VISCIOUS				0
0	0	107- 107	33	-34	-35	DUMMY STIFFNESS CONSTANT F = 0.1	-36	37
0	0	109- 109	33	ABDOMINAL VISCIOUS				0
0	0	111- 111	33	-34	-35	DUMMY STIFFNESS CONSTANT F = 0.1	-36	37
0	0	113- 113	33	ABDOMINAL VISCIOUS				0
0	0	115- 115	33	-34	-35	DUMMY STIFFNESS CONSTANT F = 0.1	-36	37
0	0	117- 117	33	ABDOMINAL VISCIOUS				0
0	0	119- 119	33	-34	-35	DUMMY STIFFNESS CONSTANT F = 0.1	-36	37
0	0	121- 121	33	ABDOMINAL VISCIOUS				0
0	0	123- 123	33	-34	-35	DUMMY STIFFNESS CONSTANT F = 0.1	-36	37
0	0	125- 125	33	ABDOMINAL VISCIOUS				0
0	0	127- 127	33	-34	-35	DUMMY STIFFNESS CONSTANT F = 0.1	-36	37
0	0	129- 129	33	ABDOMINAL VISCIOUS				0
0	0	131- 131	33	-34	-35	DUMMY STIFFNESS CONSTANT F = 0.1	-36	37
0	0	133- 133	33	ABDOMINAL VISCIOUS				0
0	0	135- 135	33	-34	-35	DUMMY STIFFNESS CONSTANT F = 0.1	-36	37
0	0	137- 137	33	ABDOMINAL VISCIOUS				0
0	0	139- 139	33	-34	-35	DUMMY STIFFNESS CONSTANT F = 0.1	-36	37
0	0	141- 141	33	ABDOMINAL VISCIOUS				0
0	0	143- 143	33	-34	-35	DUMMY STIFFNESS CONSTANT F = 0.1	-36	37
0	0	145- 145	33	ABDOMINAL VISCIOUS				0
0	0	147- 147	33	-34	-35	DUMMY STIFFNESS CONSTANT F = 0.1	-36	37
0	0	149- 149	33	ABDOMINAL VISCIOUS				0
0	0	151- 151	33	-34	-35	DUMMY STIFFNESS CONSTANT F = 0.1	-36	37

0	UT DUMMY ABSORPTION	LLA CONSTANT = 0.0	ABDOMINAL VISCIOUS	DUMMY STIFFNESS CONSTANT F = 0.1	0
3- 3	6- 6	33	-34	-36	37
UT DUMMY ABSORPTION	RUL CONSTANT = 0.0		ABDOMINAL VISCIOUS	DUMMY STIFFNESS CONSTANT F = 0.1	0
0	3- 3	9- 9	-34	-36	37
UT DUMMY ABSORPTION	LUL CONSTANT = 0.0	33	ABDOMINAL VISCIOUS	DUMMY STIFFNESS CONSTANT F = 0.1	0
0	5- 5	13- 13	-34	-36	37
H DUMMY ABSORPTION	RLA CONSTANT = 0.0	33	ABDOMINAL VISCIOUS	DUMMY STIFFNESS CONSTANT F = 0.1	0
0	5- 5	15- 15	-34	-36	37
H DUMMY ABSORPTION	LLA CONSTANT = 0.0	33	ABDOMINAL VISCIOUS	DUMMY STIFFNESS CONSTANT F = 0.1	0
0	5- 5	16- 16	-34	-36	37
H DUMMY ABSORPTION	RHD CONSTANT = 0.0	33	ABDOMINAL VISCIOUS	DUMMY STIFFNESS CONSTANT F = 0.1	0
0	5- 5	17- 17	-34	-36	37
H DUMMY ABSORPTION	LHD CONSTANT = 0.0	33	ABDOMINAL VISCIOUS	DUMMY STIFFNESS CONSTANT F = 0.1	0
0	6- 6	12- 12	-34	-36	37
RUL DUMMY ABSORPTION	RUA CONSTANT = 0.0	33	ABDOMINAL VISCIOUS	DUMMY STIFFNESS CONSTANT F = 0.1	0
0	6- 6	13- 13	-34	-36	37
RUL DUMMY ABSORPTION	RLA CONSTANT = 0.0	33	ABDOMINAL VISCIOUS	DUMMY STIFFNESS CONSTANT F = 0.1	0
0	6- 6	16- 16	-34	-36	37
RUL DUMMY ABSORPTION	RHD CONSTANT = 0.0	33	ABDOMINAL VISCIOUS	DUMMY STIFFNESS CONSTANT F = 0.1	0
0	6- 6	9- 9	-34	-36	37
RUL DUMMY ABSORPTION	LUL CONSTANT = 0.0	33	ABDOMINAL VISCIOUS	DUMMY STIFFNESS CONSTANT F = 0.1	0
0	6- 6	17- 17	-34	-36	37
RUL DUMMY ABSORPTION	LHD CONSTANT = 0.0	33	ABDOMINAL VISCIOUS	DUMMY STIFFNESS CONSTANT F = 0.1	0
0	7- 7	10- 10	-34	-36	37
		33			0

0	7- 7	LLL CONSTANT = 0.0	ABDOMINAL VISCIOUS	DUMMY STIFFNESS CONSTANT F = 0.1	37	0
	7- 7	11- 11	-34	-36		
	RL	LF	ABDOMINAL VISCIOUS	CONSTANT F = 0.1		
	DUMMY ABSORPTION	CONSTANT = 0.0				
0	9- 9	15- 15	-34	-36	37	0
	LUL	LLA	ABDOMINAL VISCIOUS	CONSTANT F = 0.1		
	DUMMY ABSORPTION	CONSTANT = 0.0				
0	9- 9	14- 14	-34	-36	37	0
	LUL	LUA	ABDOMINAL VISCIOUS	CONSTANT F = 0.1		
	DUMMY ABSORPTION	CONSTANT = 0.0				
0	9- 9	16- 16	-34	-36	37	0
	LUL	RHD	ABDOMINAL VISCIOUS	CONSTANT F = 0.1		
	DUMMY ABSORPTION	CONSTANT = 0.0				
0	9- 9	17- 17	-34	-36	37	0
	LUL	LHD	ABDOMINAL VISCIOUS	CONSTANT F = 0.1		
	DUMMY ABSORPTION	CONSTANT = 0.0				
0	10- 10	8- 8	-34	-36	37	0
	LLL	RF	ABDOMINAL VISCIOUS	CONSTANT F = 0.1		
	DUMMY ABSORPTION	CONSTANT = 0.0				
0	13- 13	15- 15	-34	-36	37	0
	RLA	LLA	ABDOMINAL VISCIOUS	CONSTANT F = 0.1		
	DUMMY ABSORPTION	CONSTANT = 0.0				
0	13- 13	17- 17	-34	-36	37	0
	RLA	LHD	ABDOMINAL VISCIOUS	CONSTANT F = 0.1		
	DUMMY ABSORPTION	CONSTANT = 0.0				
0	13- 13	2- 2	-34	-36	37	0
	RLA	MT	ABDOMINAL VISCIOUS	CONSTANT F = 0.1		
	DUMMY ABSORPTION	CONSTANT = 0.0				
0	15- 15	16- 16	-34	-36	37	0
	LLA	RHD	ABDOMINAL VISCIOUS	CONSTANT F = 0.1		
	DUMMY ABSORPTION	CONSTANT = 0.0				
0	15- 15	2- 2	-34	-36	37	0
	LLA	MT	ABDOMINAL VISCIOUS	CONSTANT F = 0.1		
	DUMMY ABSORPTION	CONSTANT = 0.0				
0	18- 18	3- 3	-20	-16	17	0

LAR	UT	ARM RESTS.	DAMPING COEFF. C=200	RATE OF DEFLEC.	CONSTANT = 0.0	PAGE
0 18- 18	14- 14	27	-20	-21	-16	17
LAR	LUA	ARM RESTS.	DAMPING COEFF. C=200	RATE OF DEFLEC.	CONSTANT = 0.0	
0 18- 18	15- 15	27	-20	-21	-16	17
LAR	LLA	ARM RESTS.	DAMPING COEFF. C=200	RATE OF DEFLEC.	CONSTANT = 0.0	
0 18- 18	17- 17	27	-20	-21	-16	17
LAR	LHD	ARM RESTS.	DAMPING COEFF. C=200	RATE OF DEFLEC.	CONSTANT = 0.0	
0 19- 19	3- 3	27	-20	-21	-16	17
RAR	UT	ARM RESTS.	DAMPING COEFF. C=200	RATE OF DEFLEC.	CONSTANT = 0.0	
0 19- 19	12- 12	27	-20	-21	-16	17
RAR	RUA	ARM RESTS.	DAMPING COEFF. C=200	RATE OF DEFLEC.	CONSTANT = 0.0	
0 19- 19	13- 13	27	-20	-21	-16	17
RAR	RLA	ARM RESTS.	DAMPING COEFF. C=200	RATE OF DEFLEC.	CONSTANT = 0.0	
1	CONSTANT, F=0.9					
478						

THE FOLLOWING JOINT RESTORING FORCE FUNCTIONS AS DEFINED ON CARDS E.7 WILL BE USED.

154

JOINT FUNCTION

1- P 45-STANDING LUMBAR SPIN  
 2- W 45-STANDING LUMBAR SPIN  
 3- NP 46-NECK PIVOT  
 4- HP 47-HEAD PIVOT  
 5- RH 43-STANDING RIGHT HIP  
 8- LH 44-STANDING LEFT HIP  
 11- RS 41-RIGHT SHOULDER JOINT  
 13- LS 42-LEFT SHOULDER JOINT  
 1 SUBROUTINE INITIAL INPUT  
 479

PAGE

CARD G.1

ZPLT(X)	ZPLT(Y)	ZPLT(Z)	I1	J1	I2	J2	I3	SPLT(1)	SPLT(2)	SPLT(3)
0.	0.	0.	0	0	0	0	0	10.00	6.00	1.00
0 INITIAL POSITIONS										

SEGMENT	LINEAR POSITION ( IN. )			LINEAR VELOCITY ( IN./SEC. )		
G.2						
	( IREF4 REFERENCE )			( INERTIAL )		
	X	Y	Z	X	Y	Z
NO. SEG	1.50000	-2.85000	-28.06000	.00000	.00000	.00000
1 LT						
				IREF2	IREF4	
				0	0	

CARDS

2	MT	1.34123	-4.26747	-31.77581	.00000	.00000	.00000	0	0
3	UT	.97439	-2.93897	-40.11971	.00000	.00000	.00000	0	0
4	N	.59403	-2.48303	-48.81948	.00000	.00000	.00000	0	0
5	H	.38291	-1.68072	-53.61946	.00000	.00000	.00000	0	0
6	RUL	-2.34943	4.19298	-26.69936	.00000	.00000	.00000	0	0
7	RLI	-3.22346	12.60220	-20.44380	.00000	.00000	.00000	0	0
8	RF	-3.45401	13.44036	-9.12360	.00000	.00000	.00000	0	0
9	LUL	5.44608	4.20861	-27.03937	.00000	.00000	.00000	0	0
10	LLL	6.10280	12.68430	-20.84724	.00000	.00000	.00000	0	0
11	LF	6.13119	13.62648	-9.53292	.00000	.00000	.00000	0	0
12	RUA	-6.95861	-1.82842	-37.41859	.00000	.00000	.00000	0	0
13	RLA	-4.16265	1.49730	-32.03443	.00000	.00000	.00000	0	0
14	LUA	7.74932	1.22203	-39.27649	.00000	.00000	.00000	0	0
15	LLA	3.67075	3.53817	-35.29350	.00000	.00000	.00000	0	0
16	RHD	3.24257	4.45418	-31.07660	.00000	.00000	.00000	0	0
17	LHD	-4.49226	3.58474	-34.35268	.00000	.00000	.00000	0	0
18	LAR	10.50000	-3.50000	-31.75000	.00000	.00000	.00000	0	0
19	RAR	-10.50000	-3.50000	-31.75000	.00000	.00000	.00000	0	0

0 INITIAL ANGULAR ROTATION AND VELOCITY

SEGMENT ANGULAR ROTATION (DEG)  
(IYPR4 REFERENCE)

NO.	SEG	YAW	PITCH	ROLL	X	Y	Z	IYPR
1	LT	90.00000	2.50000	3.00000	.00000	.00000	.00000	1 2 3 21
2	MT	.00000	.00000	.00000	.00000	.00000	.00000	3 2 1 1
3	UT	.00000	.00000	.00000	.00000	.00000	.00000	3 2 1 2
4	N	.00000	.00000	.00000	.00000	.00000	.00000	3 2 1 3
5	H	.00000	.00000	.00000	.00000	.00000	.00000	3 2 1 4
6	RUL	5.00000	97.80000	-3.00000	.00000	.00000	.00000	3 2 -3 1
7	RLI	.00000	-100.00000	.00000	.00000	.00000	.00000	3 2 1 6
8	RF	.00000	.00000	.00000	.00000	.00000	.00000	3 2 1 7
9	LUL	-5.00000	97.80000	-3.00000	.00000	.00000	.00000	3 2 -3 1
10	LLL	.00000	-100.00000	.00000	.00000	.00000	.00000	3 2 1 9
11	LF	.00000	.00000	.00000	.00000	.00000	.00000	3 2 1 10
12	RUA	-67.00000	23.10000	-7.60000	.00000	.00000	.00000	1 2 3 3
13	RLA	-30.00000	74.00000	.00000	.00000	.00000	.00000	1 2 3 12
14	LUA	101.00000	47.15000	-10.00000	.00000	.00000	.00000	1 2 3 3
15	LLA	90.00000	80.00000	.00000	.00000	.00000	.00000	1 2 3 14
16	RHD	.00000	20.00000	-2.70000	.00000	.00000	.00000	3 2 1 13
17	LHD	.00000	-12.00000	.00000	.00000	.00000	.00000	3 2 1 15
18	LAR	.00000	.00000	.00000	.00000	.00000	.00000	3 2 1 21
19	RAR	.00000	.00000	.00000	.00000	.00000	.00000	3 2 1 21

0 LINEAR AND ANGULAR VELOCITIES HAVE BEEN SET EQUAL TO THE INITIAL VELOCITIES OF THE PRIMARY VEHICLE  
FOR ALL NONVEHICLE BODY SEGMENTS WITH IREF2 = 0. FOR NONVEHICLE SEGMENTS WITH IREF2 # 0, THE LINEAR  
AND ANGULAR VELOCITIES WERE DETERMINED BY THE VALUES OF IREF2.

0 INITIAL LENGTHS OF BELT NO. 1 AND ITS SEGMENTS ARE 34.1691 17.2227 16.9463 IN.  
0 INITIAL TANGENT POINTS IN LOCAL REFERENCE OF SEGMENT 1 ARE:

CARDS 6.3





SEGMENT	(INERTIAL)			(INERTIAL)			(INERTIAL)			(INERTIAL)			PAGE
	LINEAR POSITION ( IN. )			LINEAR VELOCITY ( IN./SEC. )			LINEAR ACCELERATIONS ( G'S )			LINEAR ACCELERATIONS ( G'S )			
	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z	
18 LAR	.0000	.0000	.0000	.00000	.00000	.00000	.00000	.00000	.00000	42.738582	-.005158	.000000	.000000
19 RAR	.0000	.0000	.0000	.00000	.00000	.00000	.00000	.00000	.00000	42.750585	-.005158	.000000	.000000
20 VEH	.0000	.0000	.0000	.00000	.00000	.00000	.00000	.00000	.00000	.009968	-.005158	.000000	.000000
1 LT	1.5000	-2.8500	-28.0600	.00000	.00000	.00000	.00000	.00000	.00000	.329369	-.946405	-1.214528	.361705
2 MT	1.3412	-4.2675	-31.7758	.00000	.00000	.00000	.00000	.00000	.00000	-.765069	-.892270	.464897	.559139
3 UT	.9744	-2.9390	-40.1197	.00000	.00000	.00000	.00000	.00000	.00000	.117308	.093034	.516524	.239210
4 N	.5940	-2.4830	-48.8195	.00000	.00000	.00000	.00000	.00000	.00000	-.085519	.155925	.528688	.938527
5 H	.3829	-1.6807	-53.6195	.00000	.00000	.00000	.00000	.00000	.00000	-.016173	.019502	.536152	.926448
6 RUL	-2.3494	4.1930	-26.6994	.00000	.00000	.00000	.00000	.00000	.00000	-.077636	.133357	-.076619	.621822
7 RLL	-3.2235	12.6022	-20.4438	.00000	.00000	.00000	.00000	.00000	.00000	.000991	.170570	.361705	.494961
8 RF	-3.4540	13.4404	-9.1236	.00000	.00000	.00000	.00000	.00000	.00000	-.057860	-.070429	.559139	.509712
9 LUL	5.4461	4.2086	-27.0394	.00000	.00000	.00000	.00000	.00000	.00000	-.147287	.404008	.239210	.800051
10 LLL	6.1028	12.6843	-20.8472	.00000	.00000	.00000	.00000	.00000	.00000	.233908	.214853	.938527	.800051
11 LF	6.1312	13.6265	-9.5329	.00000	.00000	.00000	.00000	.00000	.00000	.502253	-.109609	.926448	.800051
12 RUA	-6.9586	-1.8284	-37.4186	.00000	.00000	.00000	.00000	.00000	.00000	-.489810	.554201	.621822	.800051
13 RLA	-4.1627	1.4973	-32.0344	.00000	.00000	.00000	.00000	.00000	.00000	-.1154917	1.318745	.494961	.800051
14 LUA	7.7493	.1220	-39.2765	.00000	.00000	.00000	.00000	.00000	.00000	.078353	-.057302	.509712	.800051
15 LLA	3.6708	3.5382	-35.2935	.00000	.00000	.00000	.00000	.00000	.00000	.156854	-.302094	.800051	.800051
16 RHD	3.2426	4.4542	-31.0766	.00000	.00000	.00000	.00000	.00000	.00000	-.1809961	-.065665	.365507	.800051
17 LHD	-4.4923	3.5847	-34.3527	.00000	.00000	.00000	.00000	.00000	.00000	.152008	-.186535	.785654	.800051
18 LAR	10.5000	-3.5000	-31.7500	.00000	.00000	.00000	.00000	.00000	.00000	.000424	-.002567	.720555	.800051
19 RAR	-10.5000	-3.5000	-31.7500	.00000	.00000	.00000	.00000	.00000	.00000	.000424	-.002567	.720477	.800051
20 VEH	.0000	.0000	.0000	.00000	.00000	.00000	.00000	.00000	.00000	.000000	-.003386	.001146	.80005

SEGMENT	(INERTIAL)			(LOCAL)			TOTAL
	U1 ARRAY ( IN./SEC.**2)			U2 ARRAY (RAD/SEC.**2)			
	X	Y	Z	X	Y	Z	
1 LT	-.2025D+15	.3038D+13	-.1276D+04	-.10694D+03	.98991D+02	.39954D+02	.00000D+00
2 MT	.8829D+03	-.1463D+04	.1408D+03	-.42639D+03	.61269D+03	.15204D+04	.00000D+00
3 UT	.0000D+00	.0000D+00	.3861D+03	.0000D+00	.0000D+00	.0000D+00	.00000D+00
4 N	.0000D+00	.0000D+00	.3861D+03	.0000D+00	.0000D+00	.0000D+00	.00000D+00
5 H	.0000D+00	.0000D+00	.3861D+03	.0000D+00	.0000D+00	.0000D+00	.00000D+00
6 RUL	-.1613D+13	-.2937D+13	-.3258D+03	-.80957D+01	.18905D+02	-.80978D+02	.00000D+00
7 RLL	.0000D+00	.0000D+00	.3861D+03	-.43751D+16	.94597D+34	.14019D+14	.00000D+00
8 RF	.0000D+00	.0000D+00	.3861D+03	-.11783D+14	-.44045D+16	-.13236D+14	.00000D+00
9 LUL	.2079D+02	.2050D+02	.1814D+03	.32385D+02	.17786D+02	.29110D+03	.00000D+00
10 LLL	.0000D+00	.0000D+00	.3861D+03	.10848D+14	.82537D+33	-.34760D+13	.00000D+00

	11	12	13	14	15	16	17	18	19
LF	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.0000D+00
RUA	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.0000D+00
RLA	-.6182D+03	.1025D+04	.5579D+03	.3861D+03	.3861D+03	.3861D+03	.3861D+03	.3861D+03	.3861D+03
LUA	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.0000D+00
LLA	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.0000D+00
RHD	-.3220D+03	-.3176D+03	-.1220D+04	.3861D+03	.3861D+03	.3861D+03	.3861D+03	.3861D+03	.3861D+03
LHD	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.0000D+00
LAR	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.0000D+00
RAR	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.0000D+00

JOINT	IPIN	(INERTIAL)			(INERTIAL)			(INERTIAL)			RELATIVE ANGULAR VELOCITY (RAD/SEC.)
		X	Y	Z	X	Y	Z	X	Y	Z	
1	P	0	.877D+01	-.335D+02	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.000
2	W	0	.355D+01	-.337D+02	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.000
3	NP	0	-.389D+00	.609D+00	-.586D+01	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.000
4	HP	0	-.160D+00	.193D+00	-.460D+01	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.000
5	RH	0	-.170D+01	.371D+01	-.710D+01	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.000
6	RK	1	-.152D+00	.104D+01	-.583D+01	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.000
7	RA	3	-.159D+00	-.194D+00	-.122D+01	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.000
8	LH	0	-.942D+00	.827D+01	-.526D+01	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.000
9	LK	1	.308D+01	.125D+01	-.648D+00	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.000
10	LA	3	.138D+01	-.302D+00	-.203D+00	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.000
11	RS	0	-.181D+01	-.155D+01	-.561D+01	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.000
12	RE	7	.437D+00	-.410D+01	-.388D+01	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.000
13	LS	0	.115D+01	-.165D+01	-.329D+01	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.000
14	LE	7	.792D+00	-.139D+01	-.104D+01	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.000
15	RW	3	-.126D+01	.976D+00	-.266D+00	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.000
16	LW	3	.196D+00	-.241D+00	-.277D+00	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.000
17	LR	1	.848D-03	-.513D-02	-.559D+00	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.000
18	RR	1	.848D-03	-.513D-02	-.559D+00	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.0000D+00	.000

PAGE

0 AT TIME = .000 MSEC, IEULER(12) HAS BEEN CHANGED FROM 7 TO 4  
0 AT TIME = .000 MSEC, IEULER(14) HAS BEEN CHANGED FROM 7 TO 4  
1 ELAPSED CPU TIME = 291.62 SECONDS

PAGE

1 MAIN3D FUNCTIONS FOR TIME= 10.000 MSEC

PAGE

SEGMENT	(INERTIAL)			(LOCAL)			(LOCAL)			(RAD/SEC.**2)		
	YAW	PITCH	ROLL	ANGULAR VELOCITY (RAD/SEC.)	X	Y	Z	ANGULAR ACCELERATION	X	Y	Z	
1 LT	90.0245	-2.7572	2.4018	-2.24341	.58987	.02802	-4.476438	7.077988	-4.476438	7.077988	.860740	
2 MT	90.0507	-3.0746	2.5070	.01097	-.09646	.08797	-2.134510	13.075598	-2.134510	13.075598	1.438002	
3 UT	90.0256	-3.0922	2.5486	.14961	-.29424	.09574	6.472080	-16.485284	6.472080	-16.485284	6.004483	
4 N	90.0201	-2.9375	2.4768	-.03917	.12804	.05707	5.596939	-14.514762	5.596939	-14.514762	3.706163	
5 H	89.9987	-3.0060	2.4808	-.08748	.04779	-.00218	-9.691450	20.158266	-9.691450	20.158266	1.074258	
6 RUL	-74.8620	85.4042	-170.2016	-.00571	-.13441	-.06240	.160397	1.096245	.160397	1.096245	-7.039095	
7 RLL	95.4443	-5.4016	-.7848	-.06048	.02456	.01639	-6.963888	-2.05619	-6.963888	-2.05619	1.046384	
8 RF	95.4211	-5.4794	-.7826	-.06055	-.17341	-.04702	-6.974102	-4.441306	-6.974102	-4.441306	.433218	
9 LUL	87.6327	94.9589	2.2271	-.07703	-.18612	.14241	-5.356637	-9.073388	-5.356637	-9.073388	10.585248	
10 LLL	85.4307	-4.9804	-.1932	.15356	-.00277	.05130	11.341328	-2.170373	11.341328	-2.170373	3.478066	
11 LF	85.4708	-5.0035	-.1967	.15361	-.08871	.11956	11.350319	-8.896814	11.350319	-8.896814	1.059818	
12 RUA	21.3459	2.9756	-20.5883	-.25928	-.05375	.14856	2.244796	-6.18909	2.244796	-6.18909	12.332573	
13 RLA	-53.4267	37.9568	-74.7223	-.18209	-.16718	-.20055	-16.698077	-10.347058	-16.698077	-10.347058	7.963744	
14 LUA	-172.5365	-.2248	44.4822	-.48989	-.06278	-.00834	-41.809327	-6.995660	-41.809327	-6.995660	-1.829740	
15 LLA	-82.3764	-44.4820	79.7274	-.06315	-.06611	-.50906	-7.098349	-3.906672	-7.098349	-3.906672	-43.128469	
16 RHD	-79.5145	40.5473	-94.1646	-.22376	.29336	-.08824	-14.857714	-25.099808	-14.857714	-25.099808	-3.328472	
17 LHD	80.6938	-134.6134	-88.2708	-.16687	-.06348	-.48147	-15.958614	-4.423336	-15.958614	-4.423336	-40.954376	
18 LAR	.0000	.0000	.1211	.41325	.00003	.00000	35.792192	.004245	35.792192	.004245	-.000020	
19 RAR	.0000	.0000	.1211	.41320	.00003	.00000	35.785579	.004245	35.785579	.004245	-.000020	
20 VEH	.0000	.0000	.0000	.00000	.00003	.00000	-.018540	.004246	-.018540	.004246	.000000	

SEGMENT	(INERTIAL)			(INERTIAL)			(INERTIAL)			(INERTIAL)		
	LINEAR POSITION ( IN.)	X	Y	Z	LINEAR VELOCITY ( IN./SEC.)	X	Y	Z	LINEAR ACCELERATIONS (G'S)	X	Y	Z
1 LT	1.5052	-2.8611	-28.0708	.82459	-1.64020	-1.56907	.061102	.061102	-.071389	.061102	-.071389	-.096295
2 MT	1.3481	-4.2806	-31.7750	1.11659	-2.10491	-.03844	.089811	.089811	-.176082	.089811	-.176082	-.086068
3 UT	.9754	-2.9396	-40.1166	.13973	-.15648	.37275	-.006492	-.006492	-.016094	-.006492	-.016094	-.033250
4 N	.5909	-2.4773	-48.8158	-.64371	1.23943	.48417	-.146727	-.146727	.340951	-.146727	.340951	-.006230
5 H	.3815	-1.6779	-53.6159	-.35761	.78288	.42188	-.140446	-.140446	.344811	-.140446	.344811	-.035030
6 RUL	-2.3482	4.1908	-26.7077	.24502	-.38820	-1.32580	.043914	.043914	-.042649	.043914	-.042649	-.154172
7 RLL	-3.2246	12.6014	-20.4430	-.26722	-.20775	-.12662	-.077678	-.077678	-.059432	-.077678	-.059432	-.181389
8 RF	-3.4576	13.4389	-9.1203	-.83755	-.32706	.23318	-.278520	-.278520	-.103648	-.278520	-.103648	-.162417
9 LUL	5.4450	4.2079	-27.0359	-.21941	-.17818	.64555	-.066712	-.066712	.000719	-.066712	.000719	.111327
10 LLL	6.1040	12.6839	-20.8336	.15365	-.12790	2.29987	.010159	.010159	-.031662	.010159	-.031662	.318192
11 LF	6.1399	13.6246	-9.5184	1.60935	-.42429	2.47738	.326393	.326393	-.150655	.326393	-.150655	.358424
12 RUA	-6.9646	-1.8215	-37.4135	-.91125	.98519	.75462	-.030400	-.030400	-.053863	-.030400	-.053863	.064796
13 RLA	-4.1757	1.5157	-32.0328	-1.99956	2.80882	.18766	-.096962	-.096962	.080386	-.096962	.080386	.013707
14 LUA	7.7510	.1204	-39.2711	.35679	-.43346	.96989	.108413	.108413	-.183966	.108413	-.183966	.230074
15 LLA	3.6750	3.5297	-35.2797	.89196	-1.76891	2.65706	-.250798	-.250798	-.478790	-.250798	-.478790	.624109
16 RHD	3.2251	4.4759	-31.0842	-2.71757	3.94569	-.77138	-.227187	-.227187	.506402	-.227187	.506402	-.057924
17 LHD	-4.4881	3.5803	-34.3389	.90116	-.96856	2.69642	-.259987	-.259987	-.299361	-.259987	-.299361	.682461
18 LAR	10.5000	-3.5001	-31.7363	-.00086	-.01504	2.68533	-.000348	-.000348	-.002297	-.000348	-.002297	.596589

19 RAR -10.5000 -3.5001 -31.7363 -0.0086 -0.01504 2.68556 -0.00348 -0.002296 .596725  
 20 VEH .0000 .0001 .0000 .00000 -0.00943 -0.00047 .000000 .003376 -.006350  
 1  
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SEGMENT	(INERTIAL)			(LOCAL)			U2 ARRAY (RAD/SEC.**2)			KINETIC ENERGY		
	EXTERNAL LINEAR ACCELERATIONS			EXTERNAL ANGULAR ACCELERATIONS			X Y Z			( LB.- IN.)		
	X	Y	Z	X	Y	Z	X	Y	Z	LINEAR	ANGULAR	TOTAL
1 LT	.6842D+02	-.6001D+03	-.1248D+04	.18365D+02	-.37583D+03	.34384D+02	.16550D+00			.12581D+00		.29131D+00
2 MT	.3515D+03	-.5172D+03	.2634D+03	-.10198D+04	.38077D+04	-.30466D+03	.19570D+01			.12449D+03		.19695D+01
3 UT	.0000D+00	.0000D+00	.3861D+03	-.86469D+01	.15702D+02	-.97520D+00	.92916D+02			.12494D+00		.13423D+00
4 N	.0000D+00	.0000D+00	.3861D+03	.24252D+03	-.72718D+03	.37062D+01	.75494D+02			.24383D+03		.77933D+02
5 H	.0000D+00	.0000D+00	.3861D+03	.33306D+01	.20210D+02	.54226D+01	.11804D+01			.81997D+03		.12624D+01
6 RUL	-.6399D+02	.3595D+03	-.3174D+03	-.21859D+02	.91165D+02	-.18174D+03	.50944D+01			.14930D+01		.65874D+01
7 RLL	.0000D+00	.0000D+00	.3861D+03	.14440D+01	-.21911D+02	-.46370D+02	.12240D+02			.14137D+02		.26377D+02
8 RF	.0000D+00	.0000D+00	.3861D+03	.50939D+02	.11088D+03	.48307D+02	.30795D+02			.81305D+03		.38926D+02
9 LUL	.0000D+00	.2676D+03	.3861D+03	.22221D+02	.72530D+02	.18270D+03	.12853D+01			.37379D+01		.50231D+01
10 LLL	.0000D+00	.0000D+00	.3861D+03	-.15660D+01	-.19227D+02	.50256D+02	.49948D+01			.81216D+02		.58070D+01
11 LF	.0000D+00	.0000D+00	.3861D+03	-.47389D+02	.49035D+02	-.49398D+02	.31792D+01			.49388D+03		.32286D+01
12 RUA	.0000D+00	.0000D+00	.3861D+03	.32586D+02	.23825D+01	.65366D+01	.14112D+01			.36248D+02		.17737D+01
13 RLA	-.2462D+03	.3622D+03	.4720D+03	-.36968D+02	.96359D+02	.68107D+03	.58675D+01			.37834D+02		.62458D+01
14 LUA	.0000D+00	.0000D+00	.3861D+03	.10081D+02	.29936D+01	-.11742D+02	.74765D+02			.12487D+01		.19964D+01
15 LLA	.0000D+00	.0000D+00	.3861D+03	-.79214D+00	.89448D+01	.38155D+02	.54057D+01			.14679D+02		.55525D+01
16 RHD	-.2227D+03	-.3819D+03	-.9030D+03	-.38769D+02	-.83139D+03	-.21449D+03	.39341D+01			.61547D+03		.39956D+01
17 LHD	.0000D+00	.0000D+00	.3861D+03	-.10291D+02	-.71227D+01	-.22771D+02	.15070D+01			.54324D+03		.15614D+01
18 LAR	.0000D+00	.0000D+00	.3861D+03	-.25905D+02	-.13919D+07	.10694D+04	.18678D+01			.72579D+02		.25936D+01
19 RAR	.0000D+00	.0000D+00	.3861D+03	-.25890D+02	-.13914D+07	.10692D+04	.18681D+01			.72560D+02		.25937D+01
							.58965D+00			TOTAL BODY KINETIC ENERGY		.94177D+00

JOINT	IPIN	(INERTIAL)			(INERTIAL)			JOINT TORQUES ( IN. LB.)			RELATIVE ANGULAR		
		X	Y	Z	X	Y	Z	X	Y	Z	VELOCITY	(RAD/SEC.)	
1 P	0	-.722D-01	.217D+01	-.668D+02	-.8526D+02	-.3016D+02	-.3361D+01				.734		
2 W	0	.211D+01	-.930D+00	-.648D+02	-.1581D+02	-.1440D+02	.2344D+00				.242		
3 NP	0	-.178D+01	.433D+01	-.130D+02	.1441D+02	.6526D+01	.6721D+00				.464		
4 HP	0	-.139D+01	.342D+01	-.103D+02	-.4257D+01	.3279D+00	.1132D+01				.111		
5 RH	0	.286D+01	-.202D+02	.160D+01	-.1285D+02	-.2416D+02	.1820D+01				.754		
6 RK	1	-.133D+01	.716D+00	-.118D+02	.1137D+02	-.2360D+02	-.3073D+00				.159		
7 RA	3	-.768D+00	-.286D+00	-.320D+01	-.5528D+01	-.2035D+01	.1631D+01				.208		
8 LH	0	-.244D+00	-.145D+02	-.349D+01	-.1291D+02	.3408D+02	-.7700D+01				.872		
9 LK	1	.973D+00	-.644D+00	-.670D+01	.1246D+02	.2395D+02	.5616D+00				.183		
10 LA	3	.900D+00	-.415D+00	-.177D+01	-.2313D+01	.1857D+01	-.1868D+01				.110		

11	RS	0	.237D+01	-.158D+01	-.595D+01	.3050D+01	.1344D+01	-.4624D+00	.587
12	RE	4	.251D+01	-.133D+01	-.165D+01	.2618D+01	-.1897D+02	.6852D+01	.028
13	LS	0	.179D+01	-.305D+01	-.538D+01	-.1045D+01	.2455D+00	.8158D+00	.235
14	LE	4	.129D+01	-.221D+01	-.184D+01	.1779D+01	-.8805D+01	.1013D+02	.145
15	RW	3	.451D+00	.193D+01	.294D+01	-.1077D+01	-.1267D+02	.6495D+01	.495
16	LW	3	.334D+00	-.386D+00	-.410D+00	.2015D+00	-.8795D+00	.7541D+00	.004
17	LR	1	-.697D-03	-.459D-02	-.807D+00	-.2202D+01	-.2248D-06	.4526D-02	.413
18	RR	1	-.697D-03	-.459D-02	-.807D+00	-.2201D+01	-.2220D-06	.4526D-02	.413
1 ELAPSED CPU TIME = 2902.07 SECONDS									
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PAGE

**APPENDIX D. GEBOD PROGRAM \*.TAB OUTPUT FILE (SM50H3.TAB)**

1 Seated, 50th %-ile male Hybrid III  
 OSITTING HYBRID III DUMMY (50%)  
 1 CRASH VICTIM SITTING HYBRID III

PAGE 1  
 CARDS B.2

17 SEGMENTS 16 JOINTS

SEGMENT I SYM PLOT	WEIGHT (LB.)	PRINCIPAL MOMENTS OF INERTIA (LB-SEC**2-IN)			SEMIAXES (IN.)			SEGMENT CONTACT ELLIPSIOD CENTER (IN.)			PRINCIPAL AXES (DEG)		
		X	Y	Z	X	Y	Z	X	Y	Z	YAW	PITCH	ROLL
1 LT 5	44.460	2.4575	1.2969	1.2080	5.000	7.185	4.800	-1.000	.000	.000	.00	-37.32	180.00
2 MT 4	4.890	.0612	.0593	.0205	4.775	6.500	4.000	1.000	.000	.000	.00	4.16	180.00
3 UT 3	39.216	2.6203	2.0517	1.7336	4.825	6.500	7.785	.000	.000	.000	.00	4.99	180.00
4 N 2	2.668	.0254	.0257	.0084	1.675	1.675	3.000	.000	.000	.000	.00	.00	180.00
5 H 1	9.921	.1408	.2128	.1956	4.250	2.875	4.000	.000	.000	.000	.00	-26.58	180.00
6 RUL 6	13.713	.6092	.5934	.1068	2.950	3.050	7.285	.000	.000	.000	.00	4.13	180.00
7 RLL 7	7.237	.6708	.6745	.0397	2.165	2.050	9.750	.000	.000	2.000	.00	-1.90	180.00
8 RF 8	2.756	.0067	.0524	.0491	4.900	1.675	1.675	.000	.000	.000	.96	-9.57	158.20
9 LUL 9	13.713	.6092	.5934	.1068	2.950	3.050	7.285	.000	.000	.000	.00	4.13	180.00
10 LLL 0	7.237	.6708	.6745	.0397	2.165	2.050	9.750	.000	.000	2.000	.00	-1.90	180.00
11 LF 1	2.756	.0067	.0524	.0491	4.900	1.675	1.675	.000	.000	.000	-.96	-9.57	-158.20
12 RUA 2	4.597	.1024	.0997	.0109	1.900	1.800	6.000	.000	.000	-1.000	.00	-1.31	180.00
13 RLA 3	3.800	.1191	.1128	.0069	1.775	1.775	5.800	.000	.000	.000	.00	-1.31	180.00
14 LUA 4	4.597	.1024	.0997	.0109	1.900	1.800	6.000	.000	.000	-1.000	.00	-1.31	180.00
15 LLA 5	3.800	.1191	.1128	.0069	1.775	1.775	5.800	.000	.000	.000	.00	-1.31	180.00
16 RHD 6	1.290	.0114	.0093	.0036	1.000	1.870	3.650	.000	.000	.000	-5.35	30.75	173.50
17 LHD 7	1.290	.0114	.0093	.0036	1.000	1.870	3.650	.000	.000	.000	5.35	30.75	-173.50

JOINT  
 SEG(J+1)

JOINT AXIS(DEG) -  
 CARDS B.3

JOINT J SYM PLOT PIN	LOCATION( IN.) - SEG(JNT)			LOCATION( IN.) - SEG(J+1)			JOINT AXIS(DEG) - SEG(JNT)		
	X	Y	Z	X	Y	Z	YAW	PITCH	ROLL
1 P M 1 0	-2.150	.000	-1.660	-.350	.000	2.560	.00	.00	.00
2 W N 2 0	-.350	.000	-2.560	-.890	.000	5.850	.00	.00	.00
3 NP 0 3 0	.000	.000	-5.960	.000	.000	2.760	.00	.00	.00
4 HP P 4 0	.000	.000	-2.840	-.550	.000	2.000	.00	.00	.00
5 RH Q 1 0	-.110	3.150	1.240	.000	.000	-9.960	.00	90.00	.00
6 RK R 6 1	.000	.000	6.560	-.200	.000	-6.740	.00	.00	.00
7 RA S 7 -8	-.200	.000	9.650	-2.120	.000	-1.540	90.00	.00	.00
8 LH T 1 0	-.110	-3.150	1.240	.000	.000	-9.960	.00	.00	.00
9 LK U 9 1	.000	.000	6.560	-.200	.000	-6.740	.00	.00	.00
10 LA V 10 -8	-.200	.000	9.650	-2.120	.000	-1.540	90.00	.00	.00
11 RS W 3 0	-.880	7.380	-2.660	.000	.000	-5.430	.00	90.00	.00
12 RE X 12 -8	.000	.000	4.940	.000	.000	-3.670	.00	.00	.00
13 LS Y 3 0	-.880	-7.380	-2.660	.000	.000	-5.430	.00	90.00	.00
14 LE Z 14 -8	.000	.000	4.940	.000	.000	-3.670	.00	.00	.00
15 RW 13 -8	.000	.000	6.070	-.300	.000	-2.130	90.00	.00	.00
16 LW 15 -8	.000	.000	6.070	-.300	.000	-2.130	90.00	.00	.00

## 1 JOINT TORQUE CHARACTERISTICS

PAGE 2  
CARDS B.4

## FLEXURAL SPRING CHARACTERISTICS

## TORSIONAL SPRING CHARACTERISTICS

JOINT	SPRING COEF. ( IN.LB. /DEG**J) LINEAR (J=1)	QUADRATIC (J=2)	CUBIC (J=3)	ENERGY DISSIPATION COEF.	JOINT STOP (DEG)	SPRING COEF. ( IN.LB. /DEG**J) LINEAR (J=1)	QUADRATIC (J=2)	CUBIC (J=3)	ENERGY DISSIPATION COEF.	JOINT STOP (DEG)
1 P	.000	.000	.000	1.000	.000	34.380	.000	.000	1.000	.000
2 W	.000	.000	.000	1.000	.000	34.380	.000	.000	1.000	.000
3 NP	.000	.000	.000	1.000	.000	15.000	.000	.000	1.000	.000
4 HP	.000	.000	.000	1.000	.000	15.000	.000	.000	1.000	.000
5 RH	.000	.000	.000	1.000	.000	7.500	75.000	.000	1.000	55.000
6 RK	.000	2.320	.000	1.000	48.900	.000	.000	.000	1.000	.000
7 RA	1.000	10.000	10.000	1.000	27.000	.000	6.690	.000	1.000	30.000
8 LH	.000	.000	.000	1.000	.000	7.500	75.000	.000	1.000	55.000
9 LK	.000	2.320	.000	1.000	48.900	.000	.000	.000	1.000	.000
10 LA	1.000	10.000	10.000	1.000	27.000	.000	6.690	.000	1.000	30.000
11 RS	.000	.000	.000	1.000	.000	.000	100.000	100.000	1.000	125.000
12 RE	.000	20.000	20.000	1.000	52.000	.000	4.650	.000	1.000	65.300
13 LS	.000	.000	.000	1.000	.000	.000	100.000	100.000	1.000	125.000
14 LE	.000	20.000	20.000	1.000	52.000	.000	4.650	.000	1.000	65.300
15 RW	.000	.000	.000	1.000	.000	.000	4.320	.143	1.000	55.500
16 LW	.000	.000	.000	1.000	.000	.000	4.320	.143	1.000	55.500

CARDS B.5

## JOINT VISCOUS CHARACTERISTICS AND LOCK-UNLOCK CONDITIONS

JOINT	VISCOUS COEFFICIENT ( IN.LB. SEC/DEG)	COULOMB FRICTION ( IN.LB. )	COULOMB FRICTION COEF. ( IN.LB. )	FULL FRICTION ANGULAR VELOCITY (DEG/ SEC)	MAX TORQUE FOR A LOCKED JOINT ( IN.LB. )	MIN TORQUE FOR UNLOCKED JOINT ( IN.LB. )	MIN. ANG. VELOCITY (RAD/ SEC)	IMPULSE RESTITUTION COEFFICIENT
1 P	1.200	.00	.00	30.00	.00	.00	.00	.00
2 W	1.200	.00	.00	30.00	.00	.00	.00	.00
3 NP	.350	.00	.00	30.00	.00	.00	.00	.00
4 HP	.192	.00	.00	30.00	.00	.00	.00	.00
5 RH	1.000	.00	.00	30.00	.00	.00	.00	.00
6 RK	1.000	.00	.00	30.00	.00	.00	.00	.00
7 RA	.500	.00	.00	30.00	.00	.00	.00	.00
8 LH	.000	.00	.00	30.00	.00	.00	.00	.00
9 LK	1.000	.00	.00	30.00	.00	.00	.00	.00
	1.000	.00	.00	30.00	.00	.00	.00	.00



SEGMENT NO. SYM	SEGMENT INTEGRATION CONVERGENCE TEST INPUT										PAGE 3 CARDS B.6			
	ANGULAR VELOCITIES (RAD/SEC.)					LINEAR VELOCITIES (IN./SEC.)					PAGE 3 CARDS B.6			
	MAG. TEST	ABS. ERROR	REL. ERROR			MAG. TEST	ABS. ERROR	REL. ERROR			PAGE 3 CARDS B.6			
10 LA	.500	.010	.0100			.010	.010	.0100			PAGE 3 CARDS B.6			
	.500	.010	.0100			.010	.010	.0100			PAGE 3 CARDS B.6			
11 RS	.100	.010	.0100			.010	.010	.0100			PAGE 3 CARDS B.6			
12 RE	.100	.010	.0100			.010	.010	.0100			PAGE 3 CARDS B.6			
	.100	.010	.0100			.010	.010	.0100			PAGE 3 CARDS B.6			
13 LS	.100	.010	.0100			.010	.010	.0100			PAGE 3 CARDS B.6			
14 LE	.100	.010	.0100			.010	.010	.0100			PAGE 3 CARDS B.6			
	.100	.010	.0100			.010	.010	.0100			PAGE 3 CARDS B.6			
15 RW	.500	.010	.0100			.010	.010	.0100			PAGE 3 CARDS B.6			
	.500	.010	.0100			.010	.010	.0100			PAGE 3 CARDS B.6			
	.500	.010	.0100			.010	.010	.0100			PAGE 3 CARDS B.6			
16 LW	.500	.010	.0100			.010	.010	.0100			PAGE 3 CARDS B.6			
	.500	.010	.0100			.010	.010	.0100			PAGE 3 CARDS B.6			
	.000	.010	.0100			.010	.010	.0100			PAGE 3 CARDS B.6			

1

SEGMENT NO. SYM	ANGULAR VELOCITIES (RAD/SEC.)					LINEAR VELOCITIES (IN./SEC.)					ANGULAR ACCELERATIONS (RAD/SEC.**2)					LINEAR ACCELERATIONS (IN./SEC.**2)					PAGE 4 CARD D.1				
	MAG. TEST	ABS. ERROR	REL. ERROR			MAG. TEST	ABS. ERROR	REL. ERROR			MAG. TEST	ABS. ERROR	REL. ERROR			MAG. TEST	ABS. ERROR	REL. ERROR			PAGE 4 CARD D.1				
1 LT	.010	.010	.0100			.010	.010	.0100			.100	.100	.1000			.100	.100	.1000			PAGE 4 CARD D.1				
2 CT	.010	.010	.0100			.010	.010	.0100			.100	.100	.1000			.000	.000	.0000			PAGE 4 CARD D.1				
3 UT	.010	.010	.0100			.010	.010	.0100			.100	.100	.1000			.000	.000	.0000			PAGE 4 CARD D.1				
4 N	.010	.010	.0100			.010	.010	.0100			.100	.100	.1000			.000	.000	.0000			PAGE 4 CARD D.1				
5 H	.010	.010	.0100			.010	.010	.0100			.100	.100	.1000			.000	.000	.0000			PAGE 4 CARD D.1				
6 RUL	.010	.010	.0100			.010	.010	.0100			.100	.100	.1000			.000	.000	.0000			PAGE 4 CARD D.1				
7 RLL	.010	.010	.0100			.010	.010	.0100			.100	.100	.1000			.000	.000	.0000			PAGE 4 CARD D.1				
8 RF	.010	.010	.0100			.010	.010	.0100			.100	.100	.1000			.000	.000	.0000			PAGE 4 CARD D.1				
9 LUL	.010	.010	.0100			.010	.010	.0100			.100	.100	.1000			.000	.000	.0000			PAGE 4 CARD D.1				
10 LLL	.010	.010	.0100			.010	.010	.0100			.100	.100	.1000			.000	.000	.0000			PAGE 4 CARD D.1				
11 LF	.010	.010	.0100			.010	.010	.0100			.100	.100	.1000			.000	.000	.0000			PAGE 4 CARD D.1				
12 RUA	.010	.010	.0100			.010	.010	.0100			.100	.100	.1000			.000	.000	.0000			PAGE 4 CARD D.1				
13 RLA	.010	.010	.0100			.010	.010	.0100			.100	.100	.1000			.000	.000	.0000			PAGE 4 CARD D.1				
14 LUA	.010	.010	.0100			.010	.010	.0100			.100	.100	.1000			.000	.000	.0000			PAGE 4 CARD D.1				
15 LLA	.010	.010	.0100			.010	.010	.0100			.100	.100	.1000			.000	.000	.0000			PAGE 4 CARD D.1				
16 LLL	.010	.010	.0100			.010	.010	.0100			.100	.100	.1000			.000	.000	.0000			PAGE 4 CARD D.1				
17 .ai	.010	.010	.0100			.010	.010	.0100			.100	.100	.1000			.000	.000	.0000			PAGE 4 CARD D.1				
1 NPL	NBLT	NBAG	NELP	NQ		NSD	NHRNSS	NWINDF	NJNTF	NFORCE	XXXX	XXXX	XXXX	XXXX		XXXX	XXXX	XXXX	XXXX	XXXX	PAGE 4 CARD D.1				

1 FUNCTION NO. 1 HEAD SURFACE

D0	D1	D2	D3	D4
.0000	.7100	-.8000	.0000	.0000
- FIRST PART OF FUNCTION - 5TH DEGREE POLYNOMIAL				
A0	A1	A2	A3	A5
.257000E+01	-.175980E+03	.4495670E+04	-.8953110E+04	.6029590E+04
- SECOND PART OF FUNCTION - 3 TABULAR POINTS				

0	F(0)
.710000	358.0000
.750000	3580.0000
.800000	35800.0000

FUNCTION NO. 2 BACK OF SHOULDER

D0	D1	D2	D3	D4
.0000	1.6200	-1.7000	.0000	.0000
- FIRST PART OF FUNCTION - 5TH DEGREE POLYNOMIAL				
A0	A1	A2	A3	A5
.100000E-01	-.265900E+02	.3809100E+03	-.6782200E+03	.4565300E+03
- SECOND PART OF FUNCTION - 3 TABULAR POINTS				

0	F(0)
1.620000	48.3000
1.650000	483.0000
1.700000	4830.0000

1 FUNCTION NO. 3 CHEST

D0	D1	D2	D3	D4
.0000	1.3100	-1.4000	.0000	.0000
- FIRST PART OF FUNCTION - 5TH DEGREE POLYNOMIAL				
A0	A1	A2	A3	A5
.550000E+00	.546000E+01	.7349000E+02	-.1501000E+02	.0000000E+00
- SECOND PART OF FUNCTION - 3 TABULAR POINTS				

0	F(0)
1.310000	158.6000
1.350000	1586.0000
1.400000	15860.0000

FUNCTION NO. 4 ANTERIOR PELVIS

D0	D1	D2	D3	D4
.0000	2.0200	-2.1000	.0000	.0000
FIRST PART OF FUNCTION - 5TH DEGREE POLYNOMIAL				
A0	A1	A2	A3	A4
-.1400000E+00	.1580000E+01	.2439000E+02	-.2933000E+02	.1376000E+02
SECOND PART OF FUNCTION - 3 TABULAR POINTS				
0	F(0)			
2.020000	89.7000			
2.050000	897.0000			
2.100000	8970.0000			

FUNCTION NO. 5 POSTERIOR PELVIS

D0	D1	D2	D3	D4
.0000	1.9600	-2.1000	.0000	.0000
FIRST PART OF FUNCTION - 5TH DEGREE POLYNOMIAL				
A0	A1	A2	A3	A4
-.7600000E+00	.3510000E+02	.4004000E+02	-.1249000E+02	.0000000E+00
SECOND PART OF FUNCTION - 3 TABULAR POINTS				
0	F(0)			
1.960000	127.8000			
2.030000	1278.0000			
2.100000	12780.0000			

FUNCTION NO. 6 UPPER ARM

D0	D1	D2	D3	D4
.0000	.8900	-1.0000	.0000	.0000
FIRST PART OF FUNCTION - 5TH DEGREE POLYNOMIAL				
A0	A1	A2	A3	A4
.1540000E+01	-.3063000E+02	.6270900E+03	-.1197700E+04	.9172300E+03
SECOND PART OF FUNCTION - 3 TABULAR POINTS				
0	F(0)			
1.960000	127.8000			
2.030000	1278.0000			
2.100000	12780.0000			

SECOND PART OF FUNCTION - 3 TABULAR POINTS

0 F(0)  
 .890000 203.1000  
 .950000 2031.0000  
 1.000000 20310.0000

1 FUNCTION NO. 7 FOREARM

D0 D1 D2 D3 D4  
 .0000 1.3100 -1.4000 .0000 .0000  
 FIRST PART OF FUNCTION - 5TH DEGREE POLYNOMIAL

A0 A1 A2 A3 A4 A5  
 -.240000E+01 .1073700E+03 -.3133600E+03 .5046100E+03 -.1963700E+03 .0000000E+00  
 SECOND PART OF FUNCTION - 3 TABULAR POINTS

0 F(0)  
 1.310000 156.2000  
 1.350000 1562.0000  
 1.400000 15620.0000

PAGE 8  
 CARDS E.1

FUNCTION NO. 8 HAND

D0 D1 D2 D3 D4  
 .0000 .3800 -.4500 .0000 .0000  
 FIRST PART OF FUNCTION - 5TH DEGREE POLYNOMIAL

A0 A1 A2 A3 A4 A5  
 -.400000E-01 -.3104000E+02 .2384470E+04 -.1019390E+05 .1917250E+05 .0000000E+00  
 SECOND PART OF FUNCTION - 3 TABULAR POINTS

0 F(0)  
 .380000 139.4000  
 .410000 1394.0000  
 .450000 13940.0000

1 FUNCTION NO. 9 UPPER LEG

D0 D1 D2 D3 D4  
 .0000 1.3100 -1.4000 .0000 .0000  
 FIRST PART OF FUNCTION - 5TH DEGREE POLYNOMIAL

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 CARDS E.1

A0	A1	A2	A3	A4	A5
- .2800000E+00	.1419000E+02	.8194000E+02	-.1226200E+03	.9873000E+02	-.2909000E+02
SECOND PART OF FUNCTION - 3 TABULAR POINTS					
0	F(0)				
1.310000	61.6000				
1.350000	616.0000				
1.400000	6160.0000				

CARDS E.1

FUNCTION NO. 10 KNEE					
D0	D1	D2	D3	D4	
.0000	.5400	-.5800	.0000	.0000	
FIRST PART OF FUNCTION - 5TH DEGREE POLYNOMIAL					
A0	A1	A2	A3	A4	A5
-.400000E-01	.2220000E+01	.8673400E+03	-.4016100E+03	.0000000E+00	.0000000E+00
SECOND PART OF FUNCTION - 3 TABULAR POINTS					
0	F(0)				
.540000	187.8000				
.560000	1878.0000				
.580000	18780.0000				

PAGE 10  
CARDS E.1

1 FUNCTION NO. 11 FRONT OF LOWER LEG					
D0	D1	D2	D3	D4	
.0000	1.7800	-1.9000	.0000	.0000	
FIRST PART OF FUNCTION - 5TH DEGREE POLYNOMIAL					
A0	A1	A2	A3	A4	A5
-.7400000E+00	.2679000E+02	.3920000E+01	.2905000E+02	.0000000E+00	.0000000E+00
SECOND PART OF FUNCTION - 3 TABULAR POINTS					
0	F(0)				
1.780000	223.6000				
1.840000	2236.0000				
1.900000	22360.0000				

## FUNCTION NO. 12 BACK OF LOWER LEG

D0 D1 D2 D3 D4  
 .0000 1.6600 -1.7500 .0000 .0000  
 - FIRST PART OF FUNCTION - 5TH DEGREE POLYNOMIAL  
 A0 A1 A2 A3 A4 A5  
 -.800000E-01 .2942000E+02 -.2080000E+01 .0000000E+00 .0000000E+00 .0000000E+00  
 - SECOND PART OF FUNCTION - 3 TABULAR POINTS

0 F(0)  
 1.660000 43.2000  
 1.700000 432.0000  
 1.750000 4320.0000

1 FUNCTION NO. 13 FOOT

D0 D1 D2 D3 D4  
 .0000 .8300 -.9500 .0000 .0000  
 - FIRST PART OF FUNCTION - 5TH DEGREE POLYNOMIAL  
 A0 A1 A2 A3 A4 A5  
 -.6800000E+00 .8275000E+02 -.7041700E+03 .3367100E+04 -.5570690E+04 .3188300E+04  
 - SECOND PART OF FUNCTION - 3 TABULAR POINTS

0 F(0)  
 .830000 121.2000  
 .890000 1212.0000  
 .950000 12120.0000

1 JOINT FORCE FUNCTION NO. 41 RIGHT SHOULDER JOINT

- FUNCTION IS COEFFICIENTS OF 3 ORDER POLYNOMIALS IN (THETA-THETA0) FOR 8 VALUES OF PHI  
 0 COEFFICIENTS OF (THETA-THETA0)\*\*N

N = 1 N = 2 N = 3

PHI	THETA	N = 1	N = 2	N = 3
-180.00	151.000	.0000000	87900.00	.0000000
-135.00	75.000	.0000000	13700.00	.0000000
-90.00	.000	.0000000	-312.0000	11800.00
-45.00	66.000	.0000000	7780.000	3010000.
.00	68.000	.0000000	22200.00	376000.0
45.00	89.000	.0000000	22000.00	.0000000
90.00	111.000	.0000000	2470.000	17600.00
135.00	153.000	.0000000	13000.00	.0000000

1 JOINT FORCE FUNCTION NO. 42 LEFT SHOULDER JOINT

- FUNCTION IS COEFFICIENTS OF 3 ORDER POLYNOMIALS IN (THETA-THETA0) FOR 8 VALUES OF PHI  
0

PHI	THETA0	N = 1	N = 2	N = 3
-180.00	151.000	.0000000	87900.00	.0000000
-135.00	153.000	.0000000	13000.00	.0000000
-90.00	111.000	.0000000	2470.000	17600.00
-45.00	89.000	.0000000	22000.00	.0000000
.00	68.000	.0000000	22200.00	376000.0
45.00	66.000	.0000000	7780.000	3010000.
90.00	.000	.0000000	-312.0000	11800.00
135.00	75.000	.0000000	13700.00	.0000000

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CARD E.7

1 JOINT FORCE FUNCTION NO. 43 SEATED RIGHT HIP

- FUNCTION IS TABULAR FOR 19 X 4 VALUES OF THETA AND PHI

PHI	THETA0	THETA	30.000	40.000	50.000
-180.00	.000	10.000	30.000	40.000	50.000
		60.000	80.000	90.000	100.000
		110.000	130.000	140.000	150.000
		160.000	180.000		
-90.00	.000	20.000	52.00000	112.0000	232.0000
		70.000	1910.000	3830.000	7670.000
		120.000	61400.00	123000.0	246000.0
		170.000	1970000.		
		20.000	119.0000	255.0000	527.0000
		70.000	4340.000	8690.000	17400.00
		120.000	139000.0	279000.0	557000.0
		170.000	4460000.		
.00	.000	2230000.	28.00000	50.00000	94.00000
		7.000000	710.0000	1410.000	2820.000
		472.0000	22500.00	45100.00	90100.00
		15400.00	721000.0		
		492000.0	18.00000	23.00000	33.00000
		17.00000	173.0000	333.0000	653.0000
		1070.000	5130.000	10300.00	20500.00
		34900.00	164000.0		
		1110000.			
.00	.000	8.000000			
		182.0000			
		5640.000			
		180000.0			
90.00	.000	7.000000			
		53.00000			
		1290.000			
		41000.00			

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CARD E.7

1 JOINT FORCE FUNCTION NO. 44 SEATED LEFT HIP

- FUNCTION IS TABULAR FOR 19 X 4 VALUES OF THETA AND PHI

PHI	THETA0	THETA
-180.00	.000	7.000000 472.0000 15400.00 492000.0 7.000000 53.00000 1290.000 41000.00 8.000000 182.0000 5640.000 180000.0 17.00000 1070.000 34900.00 1110000.
		20.000 70.000 120.000 170.000
		30.000 80.000 130.000 180.000
		50.000 100.000 150.000
		232.0000 3830.000 246000.0 33.00000 653.0000 20500.00 94.00000 2820.000 90100.00 527.0000 17400.00 557000.0

1

JOINT FORCE FUNCTION NO. 45 SEATED LUMBAR SPINE

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CARD E.7

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- FUNCTION IS TABULAR FOR 19 X 4 VALUES OF THETA AND PHI

PHI	THETA0	THETA
-180.00	.000	4600.000 27600.00 69000.00 1209800. 6800.000 40800.00 102000.0 1788400. 3000.000 18000.00 45000.00 789000.0 6800.000 40800.00
		20.000 70.000 120.000 170.000
		30.000 80.000 130.000 180.000
		50.000 100.000 150.000
		23000.00 50600.00 621000.0 34000.00 74800.00 918000.0 15000.00 33000.00 405000.0 34000.00 74800.00



102000.0 156400.0  
1788400. 3529200.

482800.0 918000.0

265200.0  
7010800.

1

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CARD E.7

JOINT FORCE FUNCTION NO. 46 NECK PIVOT

- FUNCTION IS TABULAR FOR 19 X 4 VALUES OF THETA AND PHI

PHI	THETA0	THETA	
-180.00		10.000	20.000
		60.000	70.000
		110.000	120.000
		160.000	170.000
		700.0000	1400.000
-90.00		4200.000	4900.000
		7700.000	8400.000
		29400.00	51800.00
		600.0000	1200.000
		3600.000	4200.000
.00		6600.000	7200.000
		25200.00	44400.00
		300.0000	600.0000
		1800.000	2100.000
		3300.000	3600.000
90.00		12600.00	22200.00
		600.0000	1200.000
		3600.000	4200.000
		6600.000	7200.000
		25200.00	44400.00

30.000  
80.000  
130.000  
180.000  
2100.000  
5600.000  
9800.000  
96500.00  
1800.000  
4800.000  
8400.000  
82800.00  
900.0000  
2400.000  
4200.000  
41400.00  
1800.000  
4800.000  
8400.000  
82800.00  
2400.000  
5400.000  
10800.00  
1200.000  
2700.000  
5400.000  
2400.000  
5400.000  
10800.00  
3000.000  
6000.000  
15600.00  
1500.000  
3000.000  
7800.000  
3000.000  
6000.000  
15600.00

1

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CARD E.7

JOINT FORCE FUNCTION NO. 47 HEAD PIVOT

- FUNCTION IS TABULAR FOR 19 X 4 VALUES OF THETA AND PHI

PHI	THETA0	THETA	
-180.00		10.000	20.000
		60.000	70.000
		110.000	120.000
		160.000	170.000
		490.0000	980.0000
-90.00		3780.000	4480.000
		7280.000	7980.000
		28980.00	51380.00
		600.0000	1200.000
		3600.000	4200.000

30.000  
80.000  
130.000  
180.000  
1680.000  
5180.000  
9380.000  
96180.00  
1800.000  
4800.000  
2380.000  
5880.000  
12180.00  
2400.000  
5400.000  
40.000  
90.000  
140.000  
50.000  
100.000  
150.000  
3080.000  
6580.000  
17780.00  
3000.000  
6000.000

6600.000	7200.000	8400.000	10800.00	15600.00
25200.00	44400.00	82800.00		
250.0000	500.0000	800.0000	1100.000	1400.000
1700.000	2000.000	2300.000	2600.000	2900.000
3200.000	3500.000	4100.000	5300.000	7700.000
12500.00	22100.00	41300.00		
600.0000	1200.000	1800.000	2400.000	3000.000
3600.000	4200.000	4800.000	5400.000	6000.000
6600.000	7200.000	8400.000	10800.00	15600.00
25200.00	44400.00	82800.00		

1  
19

PAGE

CARD F.5

THE FOLLOWING JOINT RESTORING FORCE FUNCTIONS AS DEFINED ON CARDS E.7 WILL BE USED.

JOINT	FUNCTION
1- P	45-SEATED LUMBAR SPINE
2- W	45-SEATED LUMBAR SPINE
3- NP	46-NECK PIVOT
4- HP	47-HEAD PIVOT
5- RH	43-SEATED RIGHT HIP
8- LH	44-SEATED LEFT HIP
11- RS	41-RIGHT SHOULDER JOINT
13- LS	42-LEFT SHOULDER JOINT

# APPENDIX E. GEBOD PROGRAM \*.AIN OUTPUT FILE (SM50H3.AIN)

17	16	SITTING HYBRID III										CARD B.1	
LT	544.4602	.45751	.29691	.2080	5.000	7.185	4.800	-1.000	.000	.000	1	CARD B.2	
		.00	-37.32	180.0									
MT	4	4.890	.0612	.0593	.0205	4.775	6.500	4.000	1.000	.000	-1.000	1	CARD B.2
		.00	4.16	180.0									
UT	339.2162	.62032	.05171	.7336	4.825	6.500	7.785	.000	.000	.000	1	CARD B.2	
		.00	4.99	180.0									
N	2	2.668	.0254	.0257	.0084	1.675	1.675	3.000	.000	.000	.000	1	CARD B.2
		.00	.00	180.0									
H	1	9.921	.1408	.2128	.1956	4.250	2.875	4.000	.000	.000	.000	1	CARD B.2
		.00	-26.58	180.0									
RUL	613.713	.6092	.5934	.1068	2.950	3.050	7.285	.000	.000	.000	1	CARD B.2	
		.00	4.13	180.0									
RLL	7	7.237	.6708	.6745	.0397	2.165	2.050	9.750	.000	.000	2.000	1	CARD B.2
		.00	-1.90	180.0									
RF	8	2.756	.0067	.0524	.0491	4.900	1.675	1.675	.000	.000	.000	1	CARD B.2
		.96	-9.57	158.2									
LUL	913.713	.6092	.5934	.1068	2.950	3.050	7.285	.000	.000	.000	1	CARD B.2	
		.00	4.13	180.0									
LLL	0	7.237	.6708	.6745	.0397	2.165	2.050	9.750	.000	.000	2.000	1	CARD B.2
		.00	-1.90	180.0									
LF	1	2.756	.0067	.0524	.0491	4.900	1.675	1.675	.000	.000	.000	1	CARD B.2
		-.96	-9.57	-158.2									
RUA	2	4.597	.1024	.0997	.0109	1.900	1.800	6.000	.000	.000	-1.000	1	CARD B.2
		.00	-1.31	180.0									
RLA	3	3.800	.1191	.1128	.0069	1.775	1.775	5.800	.000	.000	.000	1	CARD B.2
		.00	-1.31	180.0									
LUA	4	4.597	.1024	.0997	.0109	1.900	1.800	6.000	.000	.000	-1.000	1	CARD B.2
		.00	-1.31	180.0									
LLA	5	3.800	.1191	.1128	.0069	1.775	1.775	5.800	.000	.000	.000	1	CARD B.2
		.00	-1.31	180.0									
RHD	6	1.290	.0114	.0093	.0036	1.000	1.870	3.650	.000	.000	.000	1	CARD B.2
		-5.35	30.75	173.5									
LHD	7	1.290	.0114	.0093	.0036	1.000	1.870	3.650	.000	.000	.000	1	CARD B.2
		5.35	30.75	-173.5									
P M	1	0	-2.15	.00	-1.66	-.35	.00	2.56	0	.00	.00	CARD B.3	
		.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	0 0 0 0 0 0	
W N	2	0	-.35	.00	-2.56	-.89	.00	5.85	0	.00	.00	CARD B.3	
		.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	0 0 0 0 0 0	
NP O	3	0	.00	.00	-5.96	.00	.00	2.76	0	.00	.00	CARD B.3	
		.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	0 0 0 0 0 0	
HP P	4	0	.00	.00	-2.84	-.55	.00	2.00	0	.00	.00	CARD B.3	
		.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	0 0 0 0 0 0	
RH Q	1	0	-.11	3.15	1.24	.00	.00	-9.96	0	.00	.00	CARD B.3	
		.00	90.00	.00	.00	.00	.00	.00	.00	.00	.00	0 0 0 0 0 0	
RK R	6	1	.00	.00	6.56	-.20	.00	-6.74	0	.00	.00	CARD B.3	
		.00	.00	.00	.00	55.00	.00	.00	.00	.00	.00	0 0 0 0 0 0	
RA S	7	-8	-.20	.00	9.65	-2.12	.00	-1.54	0	.00	.00	CARD B.3	
		90.00	.00	.00	90.00	.00	.00	.00	-10.00	.00	.00	0 0 0 0 0 0	
LH T	1	0	-.11	-3.15	1.24	.00	.00	-9.96	0	.00	.00	CARD B.3	
		.00	90.00	.00	.00	.00	.00	.00	.00	.00	.00	0 0 0 0 0 0	
LK U	9	1	.00	.00	6.56	-.20	.00	-6.74	0	.00	.00	CARD B.3	
		.00	.00	.00	.00	55.00	.00	.00	.00	.00	.00	0 0 0 0 0 0	
LA V	10	-8	-.20	.00	9.65	-2.12	.00	-1.54	0	.00	.00	CARD B.3	
		90.00	.00	.00	90.00	.00	.00	.00	-10.00	.00	.00	0 0 0 0 0 0	
RS W	3	0	-.88	7.38	-2.66	.00	.00	-5.43	0	.00	.00	CARD B.3	
		.00	90.00	.00	.00	.00	.00	.00	.00	.00	.00	0 0 0 0 0 0	
RE X	12	-8	.00	.00	4.94	.00	.00	-3.67	0	.00	.00	CARD B.3	
		90.00	.00	.00	90.00	.00	.00	.00	62.50	.00	.00	0 0 0 0 0 0	
LS Y	3	0	-.88	-7.38	-2.66	.00	.00	-5.43	0	.00	.00	CARD B.3	
		.00	90.00	.00	.00	.00	.00	.00	.00	.00	.00	0 0 0 0 0 0	
LE Z	14	-8	.00	.00	4.94	.00	.00	-3.67	0	.00	.00	CARD B.3	
		90.00	.00	.00	90.00	.00	.00	.00	62.50	.00	.00	0 0 0 0 0 0	
RW	13	-8	.00	.00	6.07	-.30	.00	-2.13	0	.00	.00	CARD B.3	



XX						7XXXXXX	CARD D.1
1	HEAD SURFACE						CARD E.1
	.00	.71	-.80	.00	.00		CARD E.2
	2.57	-175.98	4495.67	-8953.11	6029.59	.00	CARD E.3
3							CARD E.4
	.71	358.00	.75	3580.00	.80	35800.00	CARD E.4
2	BACK OF SHOULDER						CARD E.1
	.00	1.62	-1.70	.00	.00		CARD E.2
	.01	-26.59	380.91	-678.22	456.53	.00	CARD E.3
3							CARD E.4
	1.62	48.30	1.65	483.00	1.70	4830.00	CARD E.4
3	CHEST						CARD E.1
	.00	1.31	-1.40	.00	.00		CARD E.2
	.55	5.46	73.49	-15.01	.00	.00	CARD E.3
3							CARD E.4
	1.31	158.60	1.35	1586.00	1.40	15860.00	CARD E.4
4	ANTERIOR PELVIS						CARD E.1
	.00	2.02	-2.10	.00	.00		CARD E.2
	-.14	1.58	24.39	-29.33	13.76	.00	CARD E.3
3							CARD E.4
	2.02	89.70	2.05	897.00	2.10	8970.00	CARD E.4
5	POSTERIOR PELVIS						CARD E.1
	.00	1.96	-2.10	.00	.00		CARD E.2
	-.76	35.10	40.04	-12.49	.00	.00	CARD E.3
3							CARD E.4
	1.96	127.80	2.03	1278.00	2.10	12780.00	CARD E.4
6	UPPER ARM						CARD E.1
	.00	.89	-1.00	.00	.00		CARD E.2
	1.54	-30.63	627.09	-1197.70	917.23	.00	CARD E.3
3							CARD E.4
	.89	203.10	.95	2031.00	1.00	20310.00	CARD E.4
7	FOREARM						CARD E.1
	.00	1.31	-1.40	.00	.00		CARD E.2
	-2.40	107.37	-313.36	504.61	-196.37	.00	CARD E.3
3							CARD E.4
	1.31	156.20	1.35	1562.00	1.40	15620.00	CARD E.4
8	HAND						CARD E.1
	.00	.38	-.45	.00	.00		CARD E.2
	-.04	-31.04	2384.47	-10193.90	19172.50	.00	CARD E.3
3							CARD E.4
	.38	139.40	.41	1394.00	.45	13940.00	CARD E.4
9	UPPER LEG						CARD E.1
	.00	1.31	-1.40	.00	.00		CARD E.2
	-.28	14.19	81.94	-122.62	98.73	-29.09	CARD E.3
3							CARD E.4
	1.31	61.60	1.35	616.00	1.40	6160.00	CARD E.4
10	KNEE						CARD E.1
	.00	.54	-.58	.00	.00		CARD E.2
	-.04	2.22	867.34	-401.61	.00	.00	CARD E.3
3							CARD E.4
	.54	187.80	.56	1878.00	.58	18780.00	CARD E.4
11	FRONT OF LOWER LEG						CARD E.1
	.00	1.78	-1.90	.00	.00		CARD E.2
	-.74	26.79	3.92	29.05	.00	.00	CARD E.3
3							CARD E.4
	1.78	223.60	1.84	2236.00	1.90	22360.00	CARD E.4
12	BACK OF LOWER LEG						CARD E.1
	.00	1.66	-1.75	.00	.00		CARD E.2
	-.08	29.42	-2.08	.00	.00	.00	CARD E.3
3							CARD E.4
	1.66	43.20	1.70	432.00	1.75	4320.00	CARD E.4
13	FOOT						CARD E.1
	.00	.83	-.95	.00	.00		CARD E.2
	-.68	82.75	-704.17	3367.10	-5570.69	3188.30	CARD E.3
3							CARD E.4
	.83	121.20	.89	1212.00	.95	12120.00	CARD E.4
9999							CARD E.1
41	RIGHT SHOULDER JOINT						CARD E.7
-4	8						CARD E.7

151.000	.000	87900.000	.000		
75.000	.000	13700.000	.000		
.000	.000	-312.000	11800.000		
66.000	.000	7780.000	3010000.000		
68.000	.000	22200.000	376000.000		
89.000	.000	22000.000	.000		
111.000	.000	2470.000	17600.000		
153.000	.000	13000.000	.000		
42	LEFT SHOULDER JOINT				CARD E.7
-4	8				CARD E.7
151.000	.000	87900.000	.000		
153.000	.000	13000.000	.000		
111.000	.000	2470.000	17600.000		
89.000	.000	22000.000	.000		
68.000	.000	22200.000	376000.000		
66.000	.000	7780.000	3010000.000		
.000	.000	-312.000	11800.000		
75.000	.000	13700.000	.000		
43	SEATED RIGHT HIP				CARD E.7
19	4				CARD E.7
.000	7.000	22.000	52.000	112.000	232.000CARD E.7
472.000	952.000	1910.000	3830.000	7670.000	15400.000CARD E.7
30700.000	61400.000	123000.000	246000.000	492000.000	983000.000CARD E.7
1970000.000					
.000	17.000	51.000	119.000	255.000	527.000CARD E.7
1070.000	2160.000	4340.000	8690.000	17400.000	34900.000CARD E.7
69700.000	139000.000	279000.000	557000.000	1110000.000	2230000.000CARD E.7
4460000.000					
.000	8.000	17.000	28.000	50.000	94.000CARD E.7
182.000	358.000	710.000	1410.000	2820.000	5640.000CARD E.7
11300.000	22500.000	45100.000	90100.000	180000.000	360000.000CARD E.7
721000.000					
.000	7.000	13.000	18.000	23.000	33.000CARD E.7
53.000	93.000	173.000	333.000	653.000	1290.000CARD E.7
2570.000	5130.000	10300.000	20500.000	41000.000	81900.000CARD E.7
164000.000					
44	SEATED LEFT HIP				CARD E.7
19	4				CARD E.7
.000	7.000	22.000	52.000	112.000	232.000CARD E.7
472.000	952.000	1910.000	3830.000	7670.000	15400.000CARD E.7
30700.000	61400.000	123000.000	246000.000	492000.000	983000.000CARD E.7
1970000.000					
.000	7.000	13.000	18.000	23.000	33.000CARD E.7
53.000	93.000	173.000	333.000	653.000	1290.000CARD E.7
2570.000	5130.000	10300.000	20500.000	41000.000	81900.000CARD E.7
164000.000					
.000	8.000	17.000	28.000	50.000	94.000CARD E.7
182.000	358.000	710.000	1410.000	2820.000	5640.000CARD E.7
11300.000	22500.000	45100.000	90100.000	180000.000	360000.000CARD E.7
721000.000					
.000	17.000	51.000	119.000	255.000	527.000CARD E.7
1070.000	2160.000	4340.000	8690.000	17400.000	34900.000CARD E.7
69700.000	139000.000	279000.000	557000.000	1110000.000	2230000.000CARD E.7
4460000.000					
45	SEATED LUMBAR SPINE				CARD E.7
19	4				CARD E.7
.000	4600.000	9200.000	13800.000	18400.000	23000.000CARD E.7
27600.000	32200.000	36800.000	41400.000	50600.000	69000.000CARD E.7
105800.000	179400.000	326600.000	621000.000	1209800.000	2387400.000CARD E.7
4742600.000					
.000	6800.000	13600.000	20400.000	27200.000	34000.000CARD E.7
40800.000	47600.000	54400.000	61200.000	74800.000	102000.000CARD E.7
156400.000	265200.000	482800.000	918000.000	1788400.000	3529200.000CARD E.7
7010800.000					
.000	3000.000	6000.000	9000.000	12000.000	15000.000CARD E.7
18000.000	21000.000	24000.000	27000.000	33000.000	45000.000CARD E.7

69000.000	117000.000	213000.000	405000.000	789000.000	1557000.000	CARD E.7
3093000.000						
.000	6800.000	13600.000	20400.000	27200.000	34000.000	CARD E.7
40800.000	47600.000	54400.000	61200.000	74800.000	102000.000	CARD E.7
156400.000	265200.000	482800.000	918000.000	1788400.000	3529200.000	CARD E.7
7010800.000						
46	NECK	PIVOT				CARD E.7
19	4					CARD E.7
.000	700.000	1400.000	2100.000	2800.000	3500.000	CARD E.7
4200.000	4900.000	5600.000	6300.000	7000.000	7700.000	CARD E.7
8400.000	9800.000	12600.000	18200.000	29400.000	51800.000	CARD E.7
96600.000						
.000	600.000	1200.000	1800.000	2400.000	3000.000	CARD E.7
3600.000	4200.000	4800.000	5400.000	6000.000	6600.000	CARD E.7
7200.000	8400.000	10800.000	15600.000	25200.000	44400.000	CARD E.7
82800.000						
.000	300.000	600.000	900.000	1200.000	1500.000	CARD E.7
1800.000	2100.000	2400.000	2700.000	3000.000	3300.000	CARD E.7
3600.000	4200.000	5400.000	7800.000	12600.000	22200.000	CARD E.7
41400.000						
.000	600.000	1200.000	1800.000	2400.000	3000.000	CARD E.7
3600.000	4200.000	4800.000	5400.000	6000.000	6600.000	CARD E.7
7200.000	8400.000	10800.000	15600.000	25200.000	44400.000	CARD E.7
82800.000						
47	HEAD	PIVOT				CARD E.7
19	4					CARD E.7
.000	490.000	980.000	1680.000	2380.000	3080.000	CARD E.7
3780.000	4480.000	5180.000	5880.000	6580.000	7280.000	CARD E.7
7980.000	9380.000	12180.000	17780.000	28980.000	51380.000	CARD E.7
96180.000						
.000	600.000	1200.000	1800.000	2400.000	3000.000	CARD E.7
3600.000	4200.000	4800.000	5400.000	6000.000	6600.000	CARD E.7
7200.000	8400.000	10800.000	15600.000	25200.000	44400.000	CARD E.7
82800.000						
.000	250.000	500.000	800.000	1100.000	1400.000	CARD E.7
1700.000	2000.000	2300.000	2600.000	2900.000	3200.000	CARD E.7
3500.000	4100.000	5300.000	7700.000	12500.000	22100.000	CARD E.7
41300.000						
.000	600.000	1200.000	1800.000	2400.000	3000.000	CARD E.7
3600.000	4200.000	4800.000	5400.000	6000.000	6600.000	CARD E.7
7200.000	8400.000	10800.000	15600.000	25200.000	44400.000	CARD E.7
82800.000						
0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	CARD F.4
45 45 46	47 43 0	0 44 0	0 41 0	42 0 0	0 0 0	CARD F.5

## APPENDIX F. MATLAB PROGRAM CCARD.M

```
% Program CCARD.M
%
% LT Douglas B. Oglesby
% 08 August 1997
%
% This program is a utility designed to facilitate the
% generation of formatted C.Cards for use in the Articulated
% Total Body (ATB) Program.
%
% The program allows any of the options specified in the
% ATB Program to be used. Input to the program is a combination
% of keyboard and text file. Output is the formatted set of C
% Cards which may be directly inserted into the ATB Program.
% Only one vehicle may be defined at a time, requiring further
% combination of multiple output files if the ATB simulation is
% to have more than one vehicle.
%
% The variable names used in this program are predominantly
% the same as those used in the ATB program. Exceptions are
% sequence control variables, flags and temporary variables.

% BEGINNING OF PROGRAM

clc
clear all

% determine the format of the data

option = menu('OPTION','Half sine wave deceleration',...
              'Tabular unidirectional deceleration',...
              'Six DOF deceleration',...
              'Spline fit position, velocity, or accel');

% card C.1 - description

disp('Enter description of crash vehicle deceleration (80 char max)')
VPSTTL = input('','s');
if length(VPSTTL) > 80
    VPSTTL = VPSTTL(1:80);
end

% card C.2

if option == 1

    ANGLE(1) = input('Azimuth of decel vector (inertial coords) in deg ');
    ANGLE(2) = input('Elevation of decel vector (intertial coords) in deg ');
    ANGLE(3) = 0;
    VIPS = input('Initial velocity (in/sec) of prescribed segment (neg - accel)
');
    VTIME = input('Time duration (sec) of decel impule ');
    if (VTIME == 0) | (VTIME == [])
        error('VTIME must not be zero or blank for option 1')
    end
    X0(1) = input('X coord (in) of vehicle reference origin (inertial) ');
    X0(2) = input('Y coord (in) of vehicle reference origin (inertial) ');
```



```

XO(3) = input('Z coord (in) of vehicle reference origin (inertial) ');
NATAB = 0;
ATO = 0;
ATD = 0;
MSEG = input('Segment # for prescribed motion (0 = primary vehicle) ');

elseif option == 2

    ANGLE(1) = input('Azimuth of decel vector (inertial coords) in deg ');
    ANGLE(2) = input('Elevation of decel vector (intertial coords) in deg ');
    ANGLE(3) = 0;
    VIPS = input('Initial velocity (in/sec) of prescribed segment (neg - accel)
');
    VTIME = 0;
    XO(1) = input('X coord (in) of vehicle reference origin (inertial) ');
    XO(2) = input('Y coord (in) of vehicle reference origin (inertial) ');
    XO(3) = input('Z coord (in) of vehicle reference origin (inertial) ');
    NATAB = input('# of tabulated values (must be odd # <=99) ');
    ATO = input('First time point (sec) ');
    ATD = input('Fixed time interval (sec) ');
    MSEG = input('Segment # for prescribed motion (0 = primary vehicle) ');

elseif option == 3

    ANGLE(1) = input('Initial yaw angle of prescribed segment (deg) ');
    ANGLE(2) = input('Initial pitch angle of prescribed segment (deg) ');
    ANGLE(3) = input('Initial roll angle of prescribed segment (deg) ');
    VIPS = input('Initial velocity (in/sec) of prescribed segment (neg - accel)
');
    VTIME = 0;
    XO(1) = input('X coord (in) of vehicle reference origin (inertial) ');
    XO(2) = input('Y coord (in) of vehicle reference origin (inertial) ');
    XO(3) = input('Z coord (in) of vehicle reference origin (inertial) ');
    NATAB = input('# of time points supplied (must be negative, <=10001) ');
    ATO = input('First time point (sec) ');
    ATD = input('Fixed time interval (sec) ');
    MSEG = input('Segment # for prescribed motion (0 = primary vehicle) ');
    LTYPE = 0;
    LFIT = 0;
    NPTS = 0;
    VMEG(1) = input('Initial angular velocity (deg/sec) about vehicle X axis ');
    VMEG(2) = input('Initial angular velocity (deg/sec) about vehicle Y axis ');
    VMEG(3) = input('Initial angular velocity (deg/sec) about vehicle Z axis ');

elseif option == 4

    ANGLE(1) = 0;
    ANGLE(2) = 0;
    ANGLE(3) = 0;
    VIPS = 0;
    VTIME = 0;
    XO(1) = 0;
    XO(2) = 0;
    XO(3) = 0;
    NATAB = input('# of time points to be computed (must be negative, <=501) ');
    ATO = input('First time point (sec) ');
    ATD = input('Fixed time interval (sec) ');
    MSEG = input('Segment # for prescribed motion (0 = primary vehicle) ');
    LTYPE = menu('Data Type', 'Position', 'Velocity', 'Acceleration');
    LFIT = input('Degree of polynomial to be used (0, 1, 2, or 3) ');
    NPTS = input('# of time point data supplied (must be <=101) ');
    VMEG(1) = 0;
    VMEG(2) = 0;

```

```

    VMEG(3) = 0;
end % of card C.2

% card C.3
if option == 2

    infile = input('Name of input file (.txt will be added) ','s');
    if infile == []
        for I=1:NATAB
            DEC(I) = input('Deceleration (g''s) ');
        end
    else
        eval(['load ',infile,'.txt']);
        tabdat = eval(infile);
        for I=1:NATAB
            index = find(tabdat(:,1) == (AT0 + (I-1)*ATD));
            DEC(I) = tabdat(index,2);
        end
    end

end % of card C.3

% card C.4
if option == 3

    MATAB = -NATAB;
    infile = input('Name of input file (.txt will be added) ','s');
    if infile == []
        for I=1:MATAB
            ATAB(1,I) = input('X decel (g''s) ');
            ATAB(2,I) = input('Y decel (g''s) ');
            ATAB(3,I) = input('Z decel (g''s) ');
            ATAB(4,I) = input('alpha X (deg/sec/sec) ');
            ATAB(5,I) = input('alpha Y (deg/sec/sec) ');
            ATAB(6,I) = input('alpha Z (deg/sec/sec) ');
        end
    else
        eval(['load ',infile,'.txt']);
        tabdat = eval(infile);
        % for I=1:MATAB
        %     index = find(abs(tabdat(:,1)-(AT0 + (I-1)*ATD)) < 1e-6);
        %     ATAB(1:6,I) = tabdat(index,2:7)';
        % end
        ATAB(1:6,1:MATAB) = tabdat(1:MATAB,2:7)';
    end

end % of card C.4

% card C.5
if option == 4

    infile = input('Name of input file (.txt will be added) ','s');
    if LTYPE == 1
        K=0;
    end
    if (LTYPE == 2) | (LTYPE == 3)
        T(1) = 0;
        XYZ(1,1) = input('Initial X position (in) of vehicle origin ');
        XYZ(2,1) = input('Initial Y position (in) of vehicle origin ');

```

```

XYZ(3,1) = input('Initial Z position (in) of vehicle origin ');
XYZ(4,1) = input('Initial yaw (deg) of vehicle coord system ');
XYZ(5,1) = input('Initial pitch (deg) of vehicle coord system ');
XYZ(6,1) = input('Initial roll (deg) of vehicle coord system ');
K = 1;
end
if LTYPE == 3
    T(2) = 0;
    XYZ(1,1) = input('Initial X velocity (in/sec) of vehicle origin ');
    XYZ(2,1) = input('Initial Y velocity (in/sec) of vehicle origin ');
    XYZ(3,1) = input('Initial Z velocity (in/sec) of vehicle origin ');
    XYZ(4,1) = input('Initial omega X (deg/sec) of vehicle coord system ');
    XYZ(5,1) = input('Initial omega Y (deg/sec) of vehicle coord system ');
    XYZ(6,1) = input('Initial omega Z (deg/sec) of vehicle coord system ');
    K = 2;
end

if infile == []
    for I=1:NPTS
        T(I+K) = input('Time (sec) ');
        if LTYPE == 1
            XYZ(1,I+K) = input('X position (in) of vehicle origin ');
            XYZ(2,I+K) = input('Y position (in) of vehicle origin ');
            XYZ(3,I+K) = input('Z position (in) of vehicle origin ');
            XYZ(4,I+K) = input('yaw (deg) of vehicle coord system ');
            XYZ(5,I+K) = input('pitch (deg) of vehicle coord system ');
            XYZ(6,I+K) = input('roll (deg) of vehicle coord system ');
        elseif LTYPE == 2
            XYZ(1,I+K) = input('X velocity (in/sec) of vehicle origin ');
            XYZ(2,I+K) = input('Y velocity (in/sec) of vehicle origin ');
            XYZ(3,I+K) = input('Z velocity (in/sec) of vehicle origin ');
            XYZ(4,I+K) = input('omega X (deg/sec) of vehicle coord system ');
            XYZ(5,I+K) = input('omega Y (deg/sec) of vehicle coord system ');
            XYZ(6,I+K) = input('omega Z (deg/sec) of vehicle coord system ');
        elseif LTYPE == 3
            XYZ(1,I+K) = input('X accel (in/sec/sec) of vehicle origin ');
            XYZ(2,I+K) = input('Y accel (in/sec/sec) of vehicle origin ');
            XYZ(3,I+K) = input('Z accel (in/sec/sec) of vehicle origin ');
            XYZ(4,I+K) = input('alpha X (deg/sec/sec) of vehicle coord system ');
            XYZ(5,I+K) = input('alpha Y (deg/sec/sec) of vehicle coord system ');
            XYZ(6,I+K) = input('alpha Z (deg/sec/sec) of vehicle coord system ');
        end
    end
else
    eval(['load ',infile,'.txt']);
    tabdat = eval(infile);
    for I=1:NPTS
        T(I+K) = tabdat(I,1);
        XYZ(1:6,I+K) = tabdat(I,2:7);
    end
end

end % of card C.5

% create the C card file

outfile = input('Output file name (.txt will be added) ','s');
outfile = [outfile, '.txt'];
fid = fopen(outfile,'wt');

% C.1 card

fprintf(fid,'%s\n',VPSTTL);

```

```

% C.2 card

chp = [1:6;1:6;1:6];
for i = 1:3
    while ANGLE(i) >= 360
        ANGLE(i) = ANGLE(i) - 360;
    end
    while ANGLE(i) <= (-360)
        ANGLE(i) = ANGLE(i) + 360;
    end
    if (ANGLE(i) < 1.0) & (ANGLE(i) > 0.0)
        chp(i,:) = [2:7];
    elseif (ANGLE(i) < 0.0) & (ANGLE(i) > (-1.0))
        chp(i,:) = [1,3:7];
    end
end
a1 = sprintf('%0.6f',ANGLE(1));
a1 = a1(chp(1,:));
a2 = sprintf('%0.6f',ANGLE(2));
a2 = a2(chp(2,:));
a3 = sprintf('%0.6f',ANGLE(3));
a3 = a3(chp(3,:));

a4 = sprintf('%0.6f',VIPS);
if (VIPS < 1.0) & (VIPS > 0.0)
    a4 = a4(2:7);
elseif (VIPS < 0.0) & (VIPS > (-1.0))
    a4 = a4(1,3:7);
else
    a4 = a4(1:6);
end

a5 = sprintf('%0.6f',VTIME);
if (VTIME < 1.0) & (VTIME > 0.0)
    a5 = a5(2:7);
else
    a5 = a5(1:6);
end

chp = [1:6;1:6;1:6];
for i = 1:3
    if X0(i) > 999999
        error('Initial position out of range')
    elseif (X0(i) < 1.0) & (X0(i) > 0.0)
        chp(i,:) = [2:7];
    elseif (X0(i) < 0.0) & (X0(i) > (-1.0))
        chp(i,:) = [1,3:7];
    end
end
a6 = sprintf('%0.6f',X0(1));
a6 = a6(chp(1,:));
a7 = sprintf('%0.6f',X0(2));
a7 = a7(chp(2,:));
a8 = sprintf('%0.6f',X0(3));
a8 = a8(chp(3,:));

a9 = int2str(NATAB);
if NATAB > 999999
    error('NATAB out of range')
end
spc = [];
if length(a9) < 6

```

```

        for i = 1:(6-length(a9))
            spc = [spc, setstr(32)];
        end
    end
    a9 = [spc, a9];

    a10 = sprintf('%0.6f', AT0);
    if (AT0 < 1.0) & (AT0 > 0.0)
        a10 = a10(2:7);
    else
        a10 = a10(1:6);
    end

    a11 = sprintf('%0.6f', ATD);
    if (ATD < 1.0) & (ATD > 0.0)
        a11 = a11(2:7);
    else
        a11 = a11(1:6);
    end

    a12 = int2str(MSEG);
    if MSEG > 29
        error('MSEG out of range')
    end
    spc = [];
    for i = 1:(6-length(a12))
        spc = [spc, setstr(32)];
    end
    a12 = [spc, a12];

    a13 = ['          C.2a'];
    c2a = [a1, a2, a3, a4, a5, a6, a7, a8, a9, a10, a11, a12, a13];

    fprintf(fid, '%s\n', c2a);

% C.2b card

if (option == 3) | (option == 4)

    b1 = int2str(LTYPE);
    spc = [];
    for i = 1:(6-length(LTYPE))
        spc = [spc, setstr(32)];
    end
    b1 = [spc, b1];

    b2 = int2str(LFIT);
    spc = [];
    for i = 1:(6-length(LFIT))
        spc = [spc, setstr(32)];
    end
    b2 = [spc, b2];

    b3 = int2str(NPTS);
    spc = [];
    if NPTS > 101
        error('NPTS out of range')
    end
    for i = 1:(6-length(NPTS))
        spc = [spc, setstr(32)];
    end
    b3 = [spc, b3];

```

```

spc = [];
for i = 1:22
    spc = [spc, setstr(32)];
end
b4 = spc;

chp=[1:10;1:10;1:10];
for i = 1:3
    if (VMEG(i) < 1.0) & (VMEG(i) > 0.0)
        chp(i,:) = [2:11];
    elseif (VMEG(i) < 0.0) & (VMEG(i) > (-1.0))
        chp(i,:) = [1,3:11];
    end
end
b5 = sprintf('%0.10f',VMEG(1));
b5 = b5(chp(1,:));
b6 = sprintf('%0.10f',VMEG(2));
b6 = b6(chp(2,:));
b7 = sprintf('%0.10f',VMEG(3));
b7 = b7(chp(3,:));

b8 = ['          C.2b'];
c2b = [b1,b2,b3,b4,b5,b6,b7,b8];

fprintf(fid, '%2\n', c2b);

end % of C.2b card

% C.3 cards

if option == 2

    for i = 1:NATAB
        b = sprintf('%0.6f',DEC(i));
        if DEC(i) > 999999
            error('DEC(i) out of range')
        elseif (DEC(i) < 1.0) & (DEC(i) > 0.0)
            chp = [2:7];
        elseif (DEC(i) < 0.0) & (DEC(i) > (-1.0))
            chp = [1,3:7];
        else
            chp = [1:6];
        end
        a(i,:) = b(chp);
    end

    numcards = round(NATAB/12) + 1;
    for k = 1:numcards
        if k ~= numcards
            c = [];
            for i = 1:12
                c = [c, a(i+(k-1)*12,:)];
            end
            c = [c, ' C.3.', int2str(k)];
        elseif k == numcards
            c = [];
            for i = 1:(NATAB-(k-1)*12)
                c = [c, a(i+(k-1)*12,:)];
            end
        end
        fprintf(fid, '%s\n', c);
    end
end

```

```

        end

    end % of C.3 cards

    % C.4 cards

    if option == 3

        for i = 1:MATAB
            for j = 1:6
                b = sprintf('%0.10f',ATAB(j,i));
                if (ATAB(j,i) < 1.0) & (ATAB(j,i) > 0.0)
                    chp = [2:11];
                elseif (ATAB(j,i) < 0.0) & (ATAB(j,i) > (-1.0))
                    chp = [1,3:11];
                else
                    chp = [1:10];
                end
                a(j,:) = b(chp);
            end
            c = [];
            for j = 1:10
                c = [c,setstr(32)];
            end
            for j = 1:6
                c = [c,a(j,:)];
            end
            c = [c,'          C.4.',int2str(i)];

            fprintf(fid,'%s\n',c);

        end

    end % of C.4 cards

    % C.5 cards

    if option == 4

        for i = 1:(NPTS+LTYPE-1)
            a = sprintf('%0.10f',T(i));
            a = a(1:10);
            for j = 1:6
                b = sprintf('%0.10f',XYZ(j,i));
                if (XYZ(j,i) < 1.0) & (XYZ(j,i) > 0.0)
                    chp = [2:11];
                elseif (XYZ(j,i) < 0.0) & (XYZ(j,i) > (-1.0))
                    chp = [1,3:11];
                else
                    chp = [1:10];
                end
                b = b(chp);
                a = [a,b];
            end
            a = [a,'          C.5.',int2str(i)];

            fprintf(fid,'%s\n',a);
        end

    end % of C.5 cards

    status = fclose(fid);

```

% END OF PROGRAM



## APPENDIX G. EXAMPLE VIEW CONTROL FILE (S9991.VIN)

7091091

1

SHOT 9991 (TEST B)

SEATED MALE HIII DUMMY

50th PERCENTILE

SHOT 9991 SEATED 50% HIII DUMMY

0.000	0.033	1.980
-------	-------	-------

0000

0 020

0

2	2	2	2	2	2	2	2
2	2	2	2	2	2	2	2
2	9	9	2	2	2	2	2
2	2	2	2	2	2		
9	9	9	9	9	9	9	9
9	9	9	9	9	9	9	9
9	9	9	9	9	9	9	9
9	9	9	9	9	9	9	9
9	9	9	9	9	9	9	9
9	9	9	9	9	9	9	9
9	9	9	9	9	9	9	9
9	9	9	9	9	9	9	9
10							
2	2	2	2	2	2	2	2
2	2	2	2	2	2	2	2
2	2	2	2				

8 5 8 3 5 5 3 3 5 3 3 3 3 3 310101010

20

20 0 0 0.50

4	115.80
---	--------

4.0	-2.0						
-850.0	40.0	-175.0	0.0	0.0	0.0	20	2
0.00	11.0						

## APPENDIX H. EXAMPLE IMAGE SETUP FILE (S9991.SETUP)

```
Ellipsoid_ID= 1
Ellipsoid_Color= 229 159 89
Ellipsoid_ID= 2
Ellipsoid_Color= 229 159 89
Ellipsoid_ID= 3
Ellipsoid_Color= 229 159 89
Ellipsoid_ID= 4
Ellipsoid_Color= 229 159 89
Ellipsoid_ID= 5
Ellipsoid_Color= 229 159 89
Ellipsoid_ID= 6
Ellipsoid_Color= 229 159 89
Ellipsoid_ID= 7
Ellipsoid_Color= 229 159 89
Ellipsoid_ID= 8
Ellipsoid_Color= 229 159 89
Ellipsoid_ID= 9
Ellipsoid_Color= 229 159 89
Ellipsoid_ID= 10
Ellipsoid_Color= 229 159 89
Ellipsoid_ID= 11
Ellipsoid_Color= 229 159 89
Ellipsoid_ID= 12
Ellipsoid_Color= 229 159 89
Ellipsoid_ID= 13
Ellipsoid_Color= 229 159 89
Ellipsoid_ID= 14
Ellipsoid_Color= 229 159 89
Ellipsoid_ID= 15
Ellipsoid_Color= 229 159 89
Ellipsoid_ID= 16
Ellipsoid_Color= 229 159 89
Ellipsoid_ID= 17
Ellipsoid_Color= 229 159 89
Ellipsoid_ID= 18
Ellipsoid_Color= 0 0 0
Ellipsoid_ID= 19
Ellipsoid_Color= 0 0 0

Plane_ID= 1 /* Seat Bottom */
Plane_Color= 255 50 0
Plane_ID= 2 /* Seat Bottom - Front */
Plane_Color= 255 50 0
Plane_ID= 3 /* Seat Bottom - Right Side */
Plane_Color= 255 50 0
Plane_ID= 4 /* Seat Bottom - Left Side */
Plane_Color= 255 50 0
Plane_ID= 5 /* Seat Back */
Plane_Color= 255 50 0
Plane_ID= 6 /* Seat Back - Top */
Plane_Color= 255 50 0
Plane_ID= 7 /* Seat Back - Right Side */
Plane_Color= 255 50 0
Plane_ID= 8 /* Seat Back - Left Side */
Plane_Color= 255 50 0
Plane_ID= 9
Plane_Color= 125 125 125

/* Seat Bottom - Right Side */
Add_Plane= -9.5 9.25 -19.75 -9.5 9.25 -24.5 -9.5 -9.25 -24.5 -9.5 -9.25 -19.75
Attach_Plane_ID= 72
To_Segment= 20
```

```

Plane_ID= 72
Plane_Color= 255 50 0

/* Seat Bottom - Left Side */
Add_Plane= 9.5 9.25 -19.75 9.5 -9.25 -19.75 9.5 -9.25 -24.5 9.5 9.25 -24.5
Attach_Plane_ID= 73
To_Segment= 20
Plane_ID= 73
Plane_Color= 255 50 0

/* Seat Bottom - Back */
Add_Plane= 9.5 -9.25 -19.75 -9.5 -9.25 -19.75 -9.5 -9.25 -24.5 9.5 -9.25 -24.5
Attach_Plane_ID= 74
To_Segment= 20
Plane_ID= 74
Plane_Color= 255 50 0

/* Seat Bottom - Bottom */
Add_Plane= 9.5 -9.25 -19.75 9.5 9.25 -19.75 -9.5 9.25 -19.75 -9.5 -9.25 -19.75
Attach_Plane_ID= 75
To_Segment= 20
Plane_ID= 75
Plane_Color= 125 125 125

/* Seat Back - Back */
Add_Plane= 9.5 -12.27 -27.77 -9.5 -12.24 -27.77 -9.5 -14.22 -44.07 9.5 -14.22 -44.07
Attach_Plane_ID= 76
To_Segment= 20
Plane_ID= 76
Plane_Color= 125 125 125

/* Seat Back - Bottom */
Add_Plane= 9.5 -8.3 -28.25 -9.5 -8.3 -28.25 -9.5 -12.27 -27.77 9.5 -12.27 -27.77
Attach_Plane_ID= 77
To_Segment= 20
Plane_ID= 77
Plane_Color= 255 50 0

/* Pedestal */
Add_Plane= -2.72 -1.148 -5.0 -2.72 1.148 -5.0 -2.72 1.148 -19.75 -2.72 -1.148 -19.75
Attach_Plane_ID= 78
To_Segment= 20
Plane_ID= 78
Plane_Color= 125 125 125

Add_Plane= -2.72 1.148 -5.0 -1.148 2.72 -5.0 -1.148 2.72 -19.75 -2.72 1.148 -19.75
Attach_Plane_ID= 79
To_Segment= 20
Plane_ID= 79
Plane_Color= 125 125 125

Add_Plane= -1.148 2.72 -5.0 1.148 2.72 -5.0 1.148 2.72 -19.75 -1.148 2.72 -19.75
Attach_Plane_ID= 80
To_Segment= 20
Plane_ID= 80
Plane_Color= 125 125 125

Add_Plane= 1.148 2.72 -5.0 2.72 1.148 -5.0 2.72 1.148 -19.75 1.148 2.72 -19.75
Attach_Plane_ID= 81
To_Segment= 20
Plane_ID= 81
Plane_Color= 125 125 125

Add_Plane= 2.72 1.148 -5.0 2.72 -1.148 -5.0 2.72 -1.148 -19.75 2.72 1.148 -19.75
Attach_Plane_ID= 82
To_Segment= 20
Plane_ID= 82
Plane_Color= 125 125 125

```

Add\_Plane= 2.72 -1.148 -5.0 1.148 -2.72 -5.0 1.148 -2.72 -19.75 2.72 -1.148 -19.75  
Attach\_Plane\_ID= 83  
To\_Segment= 20  
Plane\_ID= 83  
Plane\_Color= 125 125 125  
  
Add\_Plane= 1.148 -2.72 -5.0 -1.148 -2.72 -5.0 -1.148 -2.72 -19.75 1.148 -2.72 -19.75  
Attach\_Plane\_ID= 84  
To\_Segment= 20  
Plane\_ID= 84  
Plane\_Color= 125 125 125  
  
Add\_Plane= -1.148 -2.72 -5.0 -2.72 -1.148 -5.0 -2.72 -1.148 -19.75 -1.148 -2.72 -19.75  
Attach\_Plane\_ID= 85  
To\_Segment= 20  
Plane\_ID= 85  
Plane\_Color= 125 125 125  
  
Background\_Color= 108 165 255  
Camera\_Position= -91.0 4.0 -46.0  
Looking\_At\_Position= -6.0 0.0 -2.0  
Camera\_Segment= 20  
Initial\_Scale= .720  
Time\_Color= 0 0 0

## LIST OF REFERENCES

1. Obergefell, Louise A., et. al., 1988, "Articulated Total Body Model Enhancements Volume 2: User's Guide," AAMRL-TR-88-043.
2. Cheng, H., et. Al., 1994, "Generator of Body Data (GEBOD) Manual," AL/CF-TR-1994-0051.
3. Leetch, B. D., and W. L. Bowman, 1983, "Articulated Total Body (ATB) "VIEW" Program Software Report, Part II, User's Guide," AAMRL-TR-81-111, Vol. 2.
4. Obergefell, Louise A., 1997, "ABCs of ATB for New Users," Proceedings of the 1997 ATB Users' Group Conference, pp. 1-29.
5. Fleck, John T., and Frank E. Butler, 1981, "VALIDATION OF THE CRASH VICTIM SIMULATOR, Volume I: Engineering Manual, Part I: Analytical Formulation," DOT-HS-806 279, Vol. 1., Part 1.
6. "Anthropomorphic Dummies for Crash and Escape System Testing," 1996, AGARD Advisory Report 330.
7. Backaitis, S. H., and H. J. Mertz, eds., Hybrid III: The First Human-Like Crash Test Dummy, 1994, Society of Automotive Engineers, Warrendale.
8. Fleck, John T., et. al., 1982, "Validation of the Crash Victim Simulator; Volume 2, Engineering Manual – Part II: Validation Effort," DOT-HS-806-280.
9. Kaleps, Ints, et. al., 1988, "Measurement of Hybrid III Dummy Properties and Analytical Simulation Data Base Development," AAMRL-TR-88-005, Armstrong Aerospace medical Research Laboratory, Wright-Patterson Air Force Base, Ohio.
10. Naval Surface Warfare Center, Carderock Division, Underwater Explosions Research Department.

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